AGRICULTURE IN THE TWENTIETH CENTURY

THESE ESSAYS are written by Sir Daniel Hall's personal friends, all of them well-known authorities on the subjects with which they deal. They cover the more important developments in the research, practice and organization of British agriculture during the twentieth century, a field in which his own work has been pre-eminent.

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A. D. Hall

AGRICULTURE
IN THE
TWENTIETH CENTURY

ESSAYS ON
RESEARCH, PRACTICE, *and* ORGANIZATION
TO BE PRESENTED TO
SIR DANIEL HALL

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PREFACE

THIS volume of essays has been planned to cover the more important developments, scientific, technical, and administrative, during the years in which Sir Daniel Hall has been a leader in the world of British agriculture. Though not a countryman born, for his earliest years were spent in industrial Lancashire, his forebears were farmers, and his first love of birds and flowers was inspired on the moors in which Rochdale was set in his boyhood. After leaving Manchester Grammar School he came to Oxford at an unusually early age, as a Scholar of Balliol, to read what was then an unfashionable school, but though Chemistry was his main preoccupation he was never the narrow specialist, and he found time to cultivate that versatility of interest which all through life has marked him out from other men.

His connexion with agriculture may be said to have begun some fifty years ago, when, after a brief excursion into teaching, he undertook the organization of technical instruction for the Surrey County Council. Here he found a kindred spirit in its first Chairman, the late Mr. E. J. Halsey, who, when the agricultural depression was at its worst, persuaded his fellow members to devote a substantial part of their Government grant for education to the foundation of an agricultural college. In collaboration with the Kent County Council, the buildings of Archbishop Kempe's collegiate foundation at Wye were purchased from the Charity Commissioners, for conversion into the South-Eastern Agricultural College, and, in 1894, he was appointed its first Principal. The purpose of the College was to give instruction in the science and art of farming to young men resident in the College, to initiate research into farming problems, and to organize an advisory service available to the farmers of Kent and Surrey. There had been very little work of this kind in the country from which he could draw guidance or inspiration, and the immediate success of the new College in all its spheres

of work, and the fact that the system of education which he devised for it served as the model for all later foundations throughout the country, is a sufficient tribute to his work there.

The physical and biological sciences in their applications to the soil and to the plant became thus his own particular field, and when the Trustees of the Lawes Agricultural Trust were seeking a successor to Sir Henry Gilbert, in 1902, as Director of the Rothamsted Experimental Station, Sir Daniel Hall was their obvious choice. Here, he followed, also, after one who represented a type now almost extinct, the man of education, means and leisure, endowed at the same time with the scientific mind and the urge to satisfy its promptings. Sir John Lawes, at his own cost and initiative, had equipped and conducted what was the finest agricultural experimental station in Europe, and in contrast to his experience at Wye, Sir Daniel Hall succeeded, at Rothamsted, to a magnificent tradition. The position of Lawes's foundation to-day, still preeminent in the world of agricultural research, is the record of his response.

It was while Sir Daniel Hall was at Rothamsted that Mr. Lloyd George conceived the idea of the Development Fund to promote the better utilization of the resources of the country. In 1909 the Development Commission was established to administer the fund, and he was appointed one of the first Commissioners. So important did this work become that in 1912 he handed over the control of Rothamsted into competent hands that he himself had trained, in order to devote himself wholly to the work of the Commission.

Here began the organization of a national scheme of agricultural research and education which will always remain a memorial to him. Arising, no doubt, from his experience of Lawes's foundation mainly for the study of soil problems, he conceived the idea of a series of State-endowed research institutes, each of them concerned with the study of some fundamental problem of agriculture, and these were set up, one by one, in various University

centres in England, Scotland, and Wales, between the years 1912 and 1923.

His connexion with central administration was made closer when, in 1917, Mr. Prothero, as President of the Board of Agriculture, made Sir Daniel Hall's appointment to the Board a condition, virtually, of his own. As Secretary first of all, and later as Chief Scientific Adviser, Sir Daniel Hall remained in Whitehall to see the Board turned into a Ministry, and to supplement the work he had done for agricultural education and research by a great scheme of extension work amongst farmers, through the Agricultural Committees of the County Councils.

In 1926 the death of Professor Bateson rendered vacant the Directorship of Mr. John Innes's foundation for horticultural research, of which Sir Daniel Hall was himself a Trustee, and at the pressing request of his colleagues he agreed to accept the post. This led, naturally, to the reduction of his activity at the Ministry, but he continued his connexion with it until 1936. His last important task there was the constitution of the Agricultural Research Council, a body which he intended should function in the sphere of agricultural research as does its prototype in the field of medical research. If the complexities of the agricultural administrative machine necessitated some concessions from the ideal organization, the Council has done much, nevertheless, to encourage agricultural research, and to facilitate the distribution of grants.

This is but a bare catalogue of the more outstanding features of Sir Daniel Hall's career. It would take too long to detail the work which he has done on many Commissions and Committees at home and abroad, on the Councils of the Royal Society, the Royal Horticultural Society, the British Association, and other learned societies. Nor is it the place in which to record his versatility and many-sidedness which must have added as much to his own pleasure in life as it has to that of his friends—English literature and poetry, Chinese pottery and Japanese prints, the music of Bach and Beethoven, the culture of tulips and

apples, the study of wild birds and wild flowers, the savour of the red and white wines of France.

In the world of agriculture, whether on the side of natural science, of technical development, or of political and economic organization, he has made a position for himself unique in his generation and almost without parallel in the long history of husbandry. This volume of essays is offered as a tribute to his work and to himself by a small group of his friends and disciples, the authors.

22 June, 1939.

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AGRICULTURE AND THE CIVIL SERVICE

By H. E. DALE

THE title of this essay is not a joke; some farmers might say that the association to which it refers is for them the very reverse of a joke. But it certainly contains one primary element of humour—the collocation of apparent incongruities. Agriculture, in Britain as elsewhere, is the oldest of industries. The Civil Service, as we know it to-day, is not a hundred years old: it has been described as the one major political creation of this country during the nineteenth century. Again, agriculture is by its nature local, diffuse, mainly dependent for success on the personal care, effort, and adaptability of the farmer, not quickly responsive to control from one centre, not easily organized in large units. The Civil Service, the administrative machinery of the State, is impersonal and anonymous, extruding filaments in the shape of inspectors and local agents of various kinds who now cover the whole country, but concentrating real power almost entirely in one small quarter of London. Its virtues are order and strength, not flexibility or freedom of personal initiative. The phrase 'farming from Whitehall', flung out as an absurdity comparable to the squaring of the circle, puts into three words the fundamental incongruity. It is a measure of the power of the current which for the last twenty years and more

> Sweeps heaven and earth and men and gods along
> Like the broad volume of the insurgent Nile

that such an industry as agriculture, in such countries as England and Scotland, should be forced into close association with the machinery of the State. If the idea of farming from Whitehall is everywhere repudiated, the National Farmers' Union itself would not deny that farming must now have constant dealings with Whitehall and its permanent inhabitants. Nor perhaps would the Union deny that the bureaucracy, if it sometimes perplexes and infuriates

the simple farmer, is on the whole considerate of agricultural interests and even beneficent so far as permitted by its masters, the politicians.

These last words point to a distinction, obvious though not clear-cut, which ought to be drawn at once. The subject of this essay is not 'Agriculture and the State', a wide field over which armies of writers and speakers have marched, leaving it a little muddy. The State under our constitution is Parliament and Ministers immediately; ultimately, the electorate. In theory, these august bodies determine policy. The Civil Service is their impersonal instrument which 'no question makes of Ayes and Noes' but does what it is told by Ministers acting for Parliamentary majorities. Policy is the domain, or at least the peculiar responsibility, of Ministers and Parliament: administration the domain of the Civil Service. This is not the place to consider this statement or to inquire how closely the facts correspond to the theory; to examine, for instance, the vague and difficult border-line between policy and administration; or to investigate the part which a few Civil Servants undoubtedly take in the determination of policy, including agricultural policy. For the present purpose, it is enough that out of the hundreds of officials employed by the two Agricultural Departments of Great Britain all but a very small number (perhaps twenty or thirty) are engaged on work which is purely administrative in the sense that the principle of doing it, and doing it by State action, has passed out of the region of political controversy and is accepted by all parties. As the phrase goes, it is work 'which raises no question of policy': Ministers and Parliament hear of it only when something happens out of the ordinary. And even the twenty or thirty Civil Servants who do have a voice in the determination of policy have no ultimate responsibility for it; whatever weight their opinions may carry with their Ministers and with the Cabinet, whatever influence they may have on the final decision, it is never in form *their* decision. A discussion of the mutual relations of agriculture and the Civil Service must therefore be mainly confined to the mass

of non-controversial administrative work which brings them together, and may properly avoid the wider questions which divide political parties and to some extent the agricultural public itself.

It is not yet seventy years since the Civil Service began to be concerned in any permanent manner with the conduct of British agriculture. It is true that a Board of Agriculture (always to be connected with the name of Arthur Young) was established so long ago as 1793; but it was a voluntary society constituted by Royal Charter, the parent of the Royal Agricultural Society of England rather than of the Ministry of Agriculture,[1] and want of money brought it to an inglorious end in 1822. Between 1836 and 1845 three Commissions with functions bearing on Agriculture were created by Act of Parliament—the Tithe Commission, the Copyhold Commission, and the Inclosure Commission. They kept their separate existence for some forty years until they were amalgamated into the Land Commission, which itself disappeared into the Ministry of Agriculture in 1889. But these bodies and the officers employed by them were concerned primarily with land tenure and taxation, and only indirectly with the use of land or production: they did not touch the farmer immediately in the conduct of his business. The contact of agriculture with the Civil Service did not really begin till 1865. In that year, the Cattle Plague Department was established under the Home Office: a year later it was transferred to the Privy Council. Its purpose was to combat the great epidemic of cattle plague or rinderpest which began in June 1865 and was not finally stamped out till two years afterwards. Although the executive work of carrying out the Orders made by the Privy Council was mainly in the hands of local authorities and their staffs, including the police, nevertheless from 1865 onward there did exist a permanent staff with purely agri-

[1] For convenience I have referred throughout to the two Agricultural Departments as the Ministry of Agriculture and the Department of Agriculture for Scotland: though the former did not become a 'Ministry', nor the latter a 'Department', till comparatively late in their history.

cultural functions, under the direct control of the central Government. Previous epidemics had produced Acts of Parliament conferring on the Privy Council power to issue Orders and Regulations; but they had left behind them no permanent Department able not only to act but also to legislate within the bounds set by Parliament. The outbreak of 1865 bequeathed to the country that beneficent legacy.

It is unnecessary to trace in detail the constitutional history of the Ministry of Agriculture from 1865 onwards. It is enough to say that the landmarks are the establishment in 1883 of a Committee of the Privy Council for Agriculture, and the consequent transformation of the Veterinary Department of the Privy Council Office into the Agricultural Department; the creation of the Board of Agriculture in 1889, with a President who was normally a member of the Cabinet and was the Board for all practical purposes (the Board in fact never met); the addition of fisheries in 1903, both in fact and in title; the establishment in 1911 of a separate Board of Agriculture for Scotland, except for diseases of animals and the Ordnance Survey; and, finally, in 1919, the reconstitution of the English Board as the Ministry of Agriculture and Fisheries. For the present purpose, it is of more interest to consider the growth of the administrative functions discharged by the Department, the nature of that growth, and the character of the staff employed to discharge them.

But first it may be well to interpolate a few sentences of explanation on one general point of some importance. The Civil Service concerned with agriculture, it may be said, is not identical with the Civil Servants employed in the Agricultural Departments. The Ministry of Health, for instance, has powers and functions in relation to milk which are of great, sometimes of painful, interest to farmers; the Ministry of Transport controls the use of agricultural vehicles on the roads; the Board of Education indirectly exercises much influence on agriculture through its power over the instruction given in rural schools. This

is perfectly true: and yet it may rightly be held that the relations of agriculture with the Civil Service are substantially its relations with the officials of the Agricultural Departments. Other Departments come into contact with agriculture only incidentally and as one among many occupations which may be followed by their 'clientèle', so to speak. When they deal with the farming community as such, they normally look to the Agricultural Departments as the farmers' intermediaries and representatives. Conversely, the agricultural community looks to the Ministry of Agriculture and the Department of Agriculture for Scotland to assist in protecting its interests where they seem to be threatened by non-agricultural authorities. It is not too much to say that all the dealings of agriculture with the central Government were and are habitually conducted through the Departments of Agriculture or in consultation with them. It naturally follows that for practical purposes the Civil Service means to the agricultural community the staff employed in the Agricultural Departments.

Until the War the functions discharged by that staff were useful and sometimes onerous, but limited in their nature and effect. The duties connected with tithe, copyhold, and inclosures, which were inherited from the Land Commission, had no close relation to the general prosperity of agriculture. The same may be said of the Ministry's conscientious but insignificant efforts to promote agricultural education; and of the energy put into the smallholdings movement within the frame given by an Act of 1907. The main work of the Civil Service for agriculture was the protection of animals and crops from disease, and its rapid extirpation when it did appear. No attempt was made to grapple with the radical evil from which, in farming opinion, British agriculture has so long suffered and still suffers—inadequate and unstable prices. It was a policy directed to assisting production, in the cheerful belief that what helped production necessarily helped the producers. It would be unfair to describe such a policy as negative; but it certainly was not positive in

the sense that the Marketing Board policy of recent years or the quantitative regulation of imports are positive. It helped farmers to produce, but not to live by their produce.

It was naturally reflected in the character of the Ministry's staff. The principal function of the Department, the prevention and eradication of disease among animals, so far as it was the direct responsibility of the Ministry, was and is discharged by means of a technical staff at head-quarters, and a corps of inspectors scattered over the country; these inspectors must now all be qualified veterinary surgeons. The prevention of disease among crops comes some way behind, both in time and in importance. The Colorado Beetle made its appearance here in 1877. It was completely defeated, but left behind it an Act of Parliament which thirty years later was extended to include all insects and other pests destructive of agricultural crops. To administer these measures the Ministry maintained a relatively small staff of Horticultural Inspectors. Into the history of their battles with disease it is unnecessary to enter. It is enough to remark that with both animal and crop diseases the Ministry has been on the whole successful. Several animal diseases (including cattle plague, which was the original enemy, and rabies) have been entirely extirpated; foot-and-mouth disease is at least under control. Among crop and plant pests, the Colorado Beetle has hitherto been kept at bay, and the ravages of wart disease among potatoes have been limited. But the point to be observed is that until the War this kind of work was the Ministry's main service to agriculture, and the Ministry's staff was therefore in the main technical.

It is true that in the two or three years before the War there were signs of a change. The institution of the Development Fund in 1910 provided for the first time money to finance new ventures. Relatively large schemes for live-stock improvement and for the extension of agricultural education and research were worked out between the Ministry of Agriculture and the Development Commissioners, and were just beginning to come into operation when the War broke out and sent elsewhere both

the men and the money required for them. There was also a significant change in the highest positions at the Ministry. Mr. (now Viscount) Runciman succeeded Lord Lincolnshire as President in 1911, and very soon afterwards Sir Sydney (now Lord) Olivier took the place of Sir Thomas Elliott as Secretary. Nevertheless, by 1914 there had not been time seriously to alter the traditional policy of the Department. It remained true that the Civil Service was asked or allowed to do little for the benefit of agriculture, and came little into contact with it, except in relation to diseases among animals or crops.

A policy of this kind was natural and probably inevitable at the time. Farmers desired to be let alone: they would not tolerate official interference except when it was clearly the only alternative to heavy losses. The politicians had no desire to touch the main problems of British agriculture if they could help it. The great victory of Free Trade in 1905, conjoined with the slow but steady rise of agriculture from the great depression of the nineties to relative stability, made it both unnecessary and politically impossible to consider the kind of economic and fiscal measures (tariffs, quantitative regulation of imports, Marketing Boards) with which we are now familiar. Against the farmer on the one side, and the politician on the other, even Civil Servants endowed with the reforming zeal and the furious energy of Sir Robert Morant would probably have been powerless to initiate, or persuade their chiefs to initiate, any new and large projects. It would perhaps be not unfair to add that the permanent official who ruled the Ministry for many years until shortly before 1914, the late Sir Thomas Elliott, though a man of high ability and strong character, was not generally supposed in his later years to welcome novelties with enthusiasm.

From the policy of abstinence it followed naturally that, for good or evil, the higher staff of the Ministry was not recruited from the ordinary examination for the First Division (now known as the Administrative Class) of the Civil Service. Vacancies were filled either by examination special to the Ministry, or by promotion from the Second

Division, or by selection. So long as the Ministry's work was confined mainly to combating animal and plant disease and to administering certain laws relating to property in land, it might plausibly be urged that there was no need and no opportunity for young men from Oxford and Cambridge, probably educated in ancient literature and philosophy. Some knowledge of animals and their ailments, or of the law and history of tithe, would be far more useful. It is doubtful whether the staff of the Department ever included any man who had entered the Civil Service by the First Division examination, until the appointment of Sir Sydney Olivier to be Secretary a year or two before the War. This difference from other Departments had various consequences, one of which was fortunate. The Ministry offered to the able and ambitious man in the Second Division a much more promising field of exertion than the older Government Offices, where thirty years ago the First Division held practically a monopoly of all the higher posts. Several Civil Servants whose names and talents are now known far outside agricultural circles would, in all probability, never have had the chances which they have used so brilliantly if in their early years they had not been allotted to the Ministry, or had not procured a transfer to it from some other Department. But there were other consequences of a less happy nature. The Ministry's higher staff, recruited by methods different from those of other Departments, at a different age and sometimes from a different social class, was rather an anomaly in the general organization of the Service. It was neither First Division nor Second Division, but something between the two. The older Departments, whose higher ranks in those days were staffed entirely from the First Division, scarcely regarded the Ministry and its staff as on the same level with themselves in the official world. The status and reputation of a Government Office among its peers vary as rapidly and are as difficult to assess as those of an Oxford college; but any Civil Servant whose memory goes back thirty years or more will probably agree that the Ministry did not rank in the hierarchy with the

Home Office or the Colonial Office or even the Local Government Board. Again, it is not unfair to conjecture that the acquiescence of the Ministry in the limited range of its activities before the War was due partly to the character of the staff. Except for the mass of clerks obtained through the Second Division and similar general examinations, the staff were mainly selected for technical qualifications and training—veterinary, horticultural, educational, and so forth. Their interests went naturally to their own special line of work, not to the development of a comprehensive policy for agriculture.

This secluded tranquillity was shattered for ever by the War. The events of 1916 and 1917 made it clear to Parliament and to every one else that the State could not afford to leave agriculture alone. Mr. Prothero (afterwards Lord Ernle) was appointed President of the Board, Mr. (now Sir Daniel) Hall became Secretary; the Food Production Department bestrode the country-side. The work of that Department marks the extreme limit of State interference with British agriculture, as known hitherto. That it operated with little friction and little real need to use its vast powers of compulsion is to be ascribed, mainly, to the patriotism and reasonableness of the landowner and farmer; but also in part to the skill and tact of the men and women who formed the staff. Although some Civil Servants held high office in the Department, and made or confirmed reputations there (the names of Sir Francis Floud and Sir Henry French will occur to all who remember those heroic days), nevertheless, it was staffed from such various sources and made such extensive use of voluntary help that neither its merits nor its failings were those of Civil Service administration. The Food Production Department was a glorious episode which stands rather apart from the historical development of the relations between agriculture and the Civil Service.

But if it stands by itself in its circumstances and character, in time it coincided with a striking change. The year 1917 saw the final disappearance of the pre-War conception of the relations of the State with agriculture. In

that year the Corn Production Act, 1917, became law, the first of a series of legislative efforts to go to the root of agricultural difficulties. Of the three main principles which it embodied—guaranteed prices, the regulation of wages, a measure of control of cultivation—the first two, in some form or another, are now parts of the agricultural policy of any possible Government; the third is in logic an obvious corollary, but has not been seriously pressed because it is in practice abhorrent to the landowner, the farmer, and the Civil Servant alike. For a brief period after the end of the War, while agricultural prices were at fantastic heights, it looked as though the days of 1913 might return; but the depression of 1920–1 destroyed that hope, as it did many others. Since then, and with one interval of comparative calm, the Ministry of Agriculture, politicians and Civil Servants alike, has been hot in the search for an agricultural policy which will satisfy reasonable farmers without evoking violent opposition from an urban electorate. Direct subsidies, tariffs, quantitative regulation of imports, trade agreements, marketing Boards—these and other expedients have been tried; but it does not look as though the problem is yet completely solved.

The new kind of task which since 1917 has been set to the Ministry of Agriculture has demanded and produced a largely new staff. Most of the old activities have continued, often with increased vigour; but they are no longer the chief, almost the only, work of the Department. Four prominent additions may be distinguished: the livestock improvement scheme; the system of agricultural education and research; the regulation of wages; and, far the most prominent of all, the organization of economic and commercial assistance to agriculture. The first two of these existed before the War, but they have been so expanded and transformed since 1918 that they may be described substantially as creations of the post-War period. The statutory regulation of agricultural wages began with the Corn Production Act of 1917, was abolished with that Act in 1921, reappeared in 1924, and seems now to be

a permanent part of agricultural economy. Finally, and for the time overshadowing everything else, there are all the economic measures with which since the War one Government after another has experimented and continues to experiment, in the effort to solve the fundamental problem of securing remunerative prices to the farmer without lowering wages or raising the cost of living.

It is impossible here to give even the briefest account of what has been done in these directions during the last twenty years; and if it were possible it would of necessity pass outside the limits of the present subject. But these changes and expansions of work have had, among others, two consequences which are highly relevant. They have required a large increase in the number of Civil Servants dealing with agriculture, and they have begun a gradual and far-reaching alteration in the character of the higher staff—the men who advise Ministers on policy and, subject to them, control the executive work of the Agricultural Departments.

Little need be said concerning the increase in numbers. Any comparison with 1918 or the years immediately following it is difficult, because the War diluted the Agricultural Departments as it did most others with temporary employees who were not all eager to depart as soon as the War was over. Some eventually disappeared from public service, some were absorbed into it; but both processes were gradual, at least until the crisis of 1920–1 forced a great and sudden effort to reduce Government expenditure. But one or two facts may be stated to illustrate the growth of the Ministry of Agriculture and its direction over a period of ten years from 1927; by that time the special work arising out of the War (mainly the provision of smallholdings for ex-service men) had ceased to be important. In that year, the staff of the Ministry of Agriculture proper (i.e. excluding part-time and industrial employees, the Ordnance Survey, and Kew Gardens) was approximately 1,400; in 1937 it was close on 1,600, in spite of the disappearance of a large block of tithe work. In 1927 the Ministry was organized in seven Divisions,

excluding Establishment and Finance; ten years later there were eleven. In 1927 one Division called the Economics Division dealt with Statistics, Labour, and Marketing; in 1937 there were two Markets Divisions, a Trade Relations and Statistical Division, and an Economics Intelligence Division.[1]

But the change in both the number and character of the higher staff during these ten years is much more significant than any general increase of numbers. In 1927 there were some thirty-five members of the administrative class of the Civil Service: in 1937 there were forty-five, and the younger men came mostly from the Administrative Class examination. In addition, the demands of the marketing and economic work (on which public attention was mainly concentrated from about 1931) produced a totally new staff of forty economists and marketing officers—some chosen for their knowledge of the trade in such commodities as meat, fruit, and poultry, but a large proportion of them young university men with degrees or diplomas in economics, commerce, or agriculture. The results of these changes are only just beginning to be felt at or near the top of the official hierarchy. The Second Secretary and the majority of Assistant Secretaries and Principals are still men who entered the Service before or about the age of twenty, direct or very nearly direct from school. It is fairly safe to prophesy that in twenty years or so university-trained men will be in a majority at or near the head of the Department, unless its present policy in recruiting the higher staff is reversed. At the same time the technical work done by the Civil Service for agriculture has not diminished, nor has the technical staff: on the contrary, it has increased.

It is not fanciful, perhaps, to connect this change with the universal recognition of the fact that in any reconstruction of the national economy agriculture must have its place. It must somehow or other be fitted into the building along with defence requirements, the export trade,

[1] Labour was bracketed with live stock, in the Live-stock and Labour Division.

food imports, merchant shipping, the prosperity of our oversea debtors, and similar necessities of our economic existence. As the question of the relationship of agriculture with the other activities of the nation is forced upon the attention of Ministers, Parliament, and the public, so the State machinery dealing with agriculture, the staffs of the Agricultural Departments, naturally assimilates itself to the Civil Service which operates the Treasury, the Dominions Office, and the Board of Trade. Such an assimilation has practical results. The cohesion of British administration is much promoted, to say the least, by the simple fact that most of the men holding positions of authority in the great Departments of State received the same kind of education, were at the same universities and colleges, and entered the Service by the same path about the same time. If a Principal Assistant Secretary in the Ministry of Health wants Treasury agreement to some slightly controversial proposal, he is likely to settle it more quickly and easily if his 'opposite number' at the Treasury is a man whom he knew when they were both undergraduates at Oxford and has known familiarly ever since then. They talk the same language, and lay their minds alongside one another with no risk of misunderstanding. It would be absurd to say that this happy relationship between Civil Servants in different (or the same) Departments is confined to those who enter the Service about the age of 22 and 23 by the Administrative Class examination; but it is reasonable to suppose that it is more naturally and more often attained in those conditions. The Government is sometimes accused of 'working in water-tight compartments' or of 'lack of co-operation' between Departments. Such charges would have more foundation if the higher Civil Service were not so homogeneous a body as it is in all the principal offices. As the Agricultural Departments come daily into closer relation with the other great Departments of State, so it becomes more natural and desirable that their high officials should not be outside the general homogeneity of the Civil Service.

If we seek for a principle governing the relations of

agriculture with the Service over the period of some seventy years during which agriculture can be said to have received from the Service any attention at all, only one general inference can be drawn from the facts: the Civil Service does for agriculture what experience shows the industry cannot do for itself—and nothing more. The economic construction of the industry as an enormous number of relatively small and isolated businesses produces two opposite effects. It makes the intervention of an outside authority armed with compulsory powers peculiarly necessary, and also peculiarly difficult. An industry organized in a few large units ruled by a few highly intelligent controllers can do by internal agreement much that is impossible for an industry which includes thousands of small men. The carelessness or selfishness of one man among these thousands may start a devastating epidemic of animal disease or prevent its early extirpation. The conscientious and enlightened majority are largely at the mercy of their less scrupulous neighbours, unless compulsion can be applied under some central authority. On the other hand, intervention by such an authority is not a task lightly to be undertaken when it means dealing with hundreds and thousands of separate businesses. It is particularly repugnant in a democratic country, where any farmer who thinks himself aggrieved by the act of any official need have no hesitation in writing to his local M.P. or his local newspaper. It may confidently be said that neither farmers nor Civil Servants have desired to extend official intervention in agriculture. But it goes on extending.

Until the War—if a little repetition may be allowed—that intervention was technical in character, and not politically controversial. Its aim was larger and better production. This line of action is still vigorously pursued—witness the recent consolidation, under the Ministry of Agriculture, of the State and local machinery for dealing with animal disease. No serious question arises on such measures, except perhaps the question (which cannot be discussed here) whether their material benefit really goes

to the farmer or soon passes to the consumer. They are obviously capable of extension, and the limit is purely empirical. But all such schemes are directed to the improvement of production: an aim which no party in this country ventures openly to oppose. They raise no fundamental question of national policy. Since the War, however, the emphasis has shifted from the question, 'How can the State assist the farmer to produce?' to the question, 'Given a fair standard of production, how can the State ensure a living to the producer?' Improvements in the technique of production go no distance to satisfy the second demand. If they are of really great significance, they pass into general use, and do nothing to mitigate either internal competition or the organized competition from overseas.

Accordingly, the history of agriculture during the last twenty years is, in the main, the history of the various attempts made by ingenious politicians and Civil Servants to raise agricultural prices, or to keep them from falling, or to compensate the farmer for their fall, without attracting too much notice from the consumer—who pays either *qua* consumer or *qua* taxpayer. No other course has been possible: it has proved easier to take butter out of a dog's mouth than to induce the distributor of agricultural produce to surrender voluntarily any substantial part of his profits, and the political power of the distributive trades is such that no Government cares to incur their hostility by applying compulsion.

It is not within the scope of this essay to trace the history of these various expedients or to examine their value. It is relevant, however, to observe that this radical change in the direction of policy has involved two consequences, which may properly be called Civil Service consequences. One has already been mentioned: the Agricultural Departments have been brought into intimate contact with other great Departments of State. The other is equally obvious: they have had to face sudden and extraordinary demands upon their staffs. They have been called on to produce men with high capacities of

two different kinds. They must have men able to advise Ministers on complicated questions, not by any means purely agricultural: and able also to accomplish one of the most difficult tasks to which any man can be set, the translation of a large decision, affecting in a novel way wide and varied interests, into a detailed scheme which will pass Parliament and will work when passed. Secondly, they must have men of high executive ability, with the organizing power, the patience, and the sense of order to create and set going new administrative machines. Any one who knows how such bodies as the Wheat Commission and the Live-stock Commission have been staffed, or how much the Marketing Boards owed in their early days to the officials of the Agricultural Departments, will recognize the kind of quality now required.

In constitutional theory the permanent official *in propria persona* is unknown to the public: he hardly exists except as an emanation from the Minister, speaking with the Minister's voice and acting as an instrument in his hand. In fact, of course, the chief officials of every Department are well known in the sphere of affairs with which their Department is concerned, and sometimes beyond it. On their personal qualities mainly depends the easy conduct of the Department's day-to-day business, including the maintenance of good relations with influential societies and individuals outside the official worlds; and also, to a less but still great extent, the rightness of the broad decisions and the success of the large measures of policy which from time to time require to be taken, not least in regard to agriculture. Reference has already been made to the gradual change which is likely, in a few years, to staff the higher offices of the Agricultural Departments mainly with non-technical men who entered the Civil Service by the same path as their 'opposite numbers' in other Departments—a change naturally conforming to the movement of opinion which has brought agriculture into the main current of national policy. But no essay on agriculture and the Civil Service would be complete without some mention of a few distinguished men who,

entering the Service by very different paths and with very different experience, have in the past devoted to British agriculture high character and great talents, not to be obscured even by the shade of a Government Office.

To those who remember the Ministry of Agriculture of thirty years ago, the scene is dominated by the grim figure of Sir Thomas Elliott. The Department, as it existed when the War broke out, may almost be said to have been his creation. His mind, with all its merits, was not perhaps very open to new ideas—at any rate in his later years. But he was a good judge of men: he brought into official life Mr. (now Sir Thomas) Middleton, who still exercises from Dean's Yard a benevolent and omniscient supervision of agricultural research. The reign of Sir T. Elliott's successor was troublous; but his times were calm in comparison with the storms of later years. In 1917 Mr. (now Sir Daniel) Hall crossed over from the Development Commission to the Ministry, to serve there for ten years, first as Secretary, then as Director-General of the Intelligence Department. His eminent reputation was and is independent of his career in the Civil Service. To regard him as a retired official would be ludicrous though accurate. He is the thinker, writer, and teacher who has inspired successive generations, in and beyond the agricultural world, with something of his own many-sided curiosity and versatile zest for excellence. Yet his official career left behind it a monument: more than any other single man, he created the great system of agricultural research which steadily advances knowledge, not only for this country. The Secretaryship came next to Sir Francis Floud. During his tenure of office the beet subsidy established a new branch of agriculture, and, incidentally, saved East Anglian farming from a great disaster; the Ministry assumed its present form of organization, which seems likely to be in essentials permanent; and above all, mainly through him and the trust which he inspired, the Ministry as a Department won the confidence and friendship of the non-official agricultural societies, and notably of the National Farmers'

Union, much the most powerful of them all. With Sir Francis Floud as permanent Head of the Ministry in London, and Sir R. Greig as chief of the Scottish Department in Edinburgh, the British farmer came to have some belief in the good sense and honesty of the Departments, whatever he might think of the Ministers in power for the time being. Finally, there are two much younger men, whose names can be no more than mentioned as they are still in the Service, though removed from the Agricultural Departments. No one who knows anything of the true history of British agriculture in recent years will fail to associate some of the most striking developments of agricultural policy and organization with the names of Sir Henry French and Sir Arthur Street.

Surveying the extension of Government (and therefore Civil Service) assistance, interference, control—whatever you like to call it—in relation to agriculture during the last twenty years and particularly since 1931, we are naturally led to ask, 'When will it stop?' The only answer possible to this uneasy question is 'Not yet'. On the side of improvements to aid production, probably little is to be expected for the present beyond some growth in the system of agricultural education and research, and stronger efforts against animal and plant diseases: both most laudable, but neither going to the root of the agricultural problem. The farmer's cry is, 'Give me reasonable prices, and I will look after production': and who shall say that he is wrong, even though he may have to contend with difficulties unknown, to the same degree at least, a generation ago? In spite of the lack of agricultural capital, the disappearance of the good landlord, the growing scarcity of skilled workmen in the vigour of manhood, nevertheless the history of British agriculture during the last few years does not suggest that it has lost the tradition of excellence. One of the major perplexities encountered in recent agricultural policy has been the speed and ability with which farmers have turned over from unprofitable forms of production to forms in which state action, or organization under the auspices of the State, has seemed

to offer a temporary guarantee of a reasonable price. The barriers set up by the Hops Marketing Board and the Potato Marketing Board to limit the influx of new-comers into their industries are unintentional testimonies to the farmer's general skill and adaptability.

But if on the side of production the farmer needs little assistance beyond that which he is now given, on the crucial matter of prices he needs a great deal. Strictly speaking, this last is not an agricultural question. In order to help a farmer to grow better crops, or to feed pigs more cheaply, or to stamp out disease among his cattle, a Civil Servant must have been trained in the technical knowledge appropriate to his particular branch of agriculture. How to get better and more stable prices for agricultural produce is a question partly for the economist, ultimately for the politician and his permanent advisers who have to decide what is administratively and financially possible, within the limits set by Parliamentary and public opinion. It is here that the Civil Servant may do most for agriculture. It is not in the least likely that we shall ever see farming from Whitehall, or even farming conducted locally but ultimately controlled from Whitehall by a Board of officials such as the Board of Inland Revenue. It is probable, however, that any large measure to stabilize and guarantee agricultural prices will be accompanied by a corresponding measure of public control. If so, the Civil Service will have two functions to perform. The chief officials of the Agricultural Departments, with the Treasury and the Board of Trade, are bound to take a large if unobtrusive part in settling the extent of that control, and the form of the authority through whom it is to be exercised. Secondly, it seems likely that the form of the authority will be a semi-independent public body (or bodies) on the model of the Wheat Commission or the Live-stock Commission. Such bodies are composed mainly or entirely of persons of eminence from outside the Government offices, but experience suggests that they themselves usually desire to obtain a proportion of their staff, including their principal officers, from the Civil Service. It would be a fair bet that

when an Agricultural Prices Regulation Commission is established, the Secretary and his principal subordinates will come from the purlieus of Whitehall. If he be able and discreet he may well become the most important figure in British agriculture, exercising on its form and destiny an influence greater than that of any other single man. The Civil Service has produced, in the past, men eminently fit to hold such a position. There is no reason to think that the supply will fail in the future.

AGRICULTURE AND THE STATE

THE FINANCIAL AND ECONOMIC RESULTS OF CONTROL

By J. A. Venn

THE changing practices, derived from scientific progress, observable in post-War British agriculture, are described by others in this volume. It seems, therefore, not inappropriate now to draw attention to some other aspects of the industry which can claim to be fundamental in any appraisement of our rural complex. I refer in particular to its financial and social economy as well as, more generally, to its present-day bearing upon other human activities, all of which have, as a direct result of State action, suffered great changes. And here may I explain that in the sub-title of this essay the term 'Control' has designedly been substituted for the arguably more correct 'Intervention' or the defensible 'Assistance', for none can aver that the policies and activities of those engaged in primary production are now as spontaneous and untrammelled as they would be had not successive Administrations, in order to counter exigencies of varying magnitude, visited agriculture, as Zeus visited Danae, in 'a shower of gold'—I borrow the simile of a well-known politician.

History and economics are frequently indissoluble. This is so in the present instance, and although, prior to an examination of the extraordinary changes brought about by the recent extension of State influence, I do not ask you retrospectively to accompany me in a study of the recognized medieval methods of controlling trade or of regulating prices and wages (some of which survived into the nineteenth century), yet I must, in order to illustrate the magnitude of the change that has taken place in the national outlook upon this subject, first effect comparison between the State's reactions to the situation confronting it at the present time and in two other comparatively modern periods of depression. I refer, of course, to (*a*) the

two disastrous decades that followed upon the Peace of 1815, and (*b*) the eighties and nineties of last century. Significantly, it is only during such times of stress—whether engendered by war or by monetary causes—that what is still the greatest industry of these islands (in its capitalization, the numbers of its employees, and the value of its output) receives any appreciable measure of recognition, for, if we exclude what is familiarly designated 'Education and Research'—a euphemism for the semi-official dissemination of scientific knowledge amongst practising agriculturists—international peace and domestic prosperity have ever tended to be accompanied by apathy and neglect of rural interests.

It is a trite, and familiar, saying that 'History repeats itself', but, in the years that followed the Napoleonic war, the legislative attempts of our forebears to counter falling prices (including a National Debt multiplied, as is ours now, tenfold), unemployment, social unrest, and many other evils only too familiar to us were, *mutatis mutandis*, and up to a point in time, remarkably similar to those which we ourselves put forward a hundred years later. It was, indeed, to the historian, a cause of surprise that, in the years 1918–22, the administrators concerned did not appear to be acquainted with the sequence of events three generations earlier; much unnecessary friction and heart-burning, many a miscalculation, involving either ultimate repeal of legislation or excessive expenditure of public funds, might, it seemed then, with a little knowledge of economic history, have been avoided. Thus, the Agriculture Act of 1920, conceived in the mistaken view that a world shortage of wheat was imminent, and guaranteeing, therefore, to home producers abnormally high prices for a considerable number of years—which, it was feared, might also be productive of further wars—had its counterpart in the equally abortive Corn Law of 1815, the aim of which was also to remunerate under peace conditions British farmers and landowners upon a war-time scale of values. Upon both occasions the officially unforeseen, or ignored, superabundance of supplies—derived in the one

case from home-produced sources, in the other from the ends of the earth—frustrated man's efforts to perpetuate artificial prices. Listen to an impatient leader-writer of *The Times* in January 1826, who wrote:

'What the nation pants for, is a sensible fall of prices. *Bread must be had cheap.* Rents must be sacrificed to the lives of the people. It is monstrous impudence to talk about the ruin of the *farmers* from a lowering in the price of produce. The farmers want nothing better than low prices, if they can but get their lands at proportionate rents. . . . The paper currency has been pushed to madness, as a temporary help to the manufacturing interest against the monopoly of corn. Leave the loaf of bread to find its own value. It is horrible to tell a starving family, "You shall have no food but at a price beyond your means of procuring it."'

In our own post-War experience the loaf found 'its own value' more quickly, and the press could soon point out that it cost but a fraction of the corresponding price on the Continent, thereby suggesting in effect that it might be too cheap. Incidentally, the policy of the now unfortunately defunct Empire Marketing Board and of Ottawa's resolutions were, in the 1815 Act, also forestalled, for thereby the effective order of preference was the familiar one of (1) home-produced, (2) Canadian, and (3) foreign (viz. European) wheat.

Again, up to 1836 (with the exception of London, where the custom had ceased in 1822) Justices of the Peace, sitting in special Assize, determined the retail price of the loaf, allowing certain margins of profit to miller and baker. Their findings were thus promulgated to our grandparents: 'The Assize of Bread for this town was reduced three farthings in the quartern loaf wheaten, the price of which is now eightpence three farthings' (*Cambridge Chronicle*, March 1822). We ourselves may correspondingly read in our morning newspapers such edicts as the following: 'The London millers announce that the current price of standard-grade flour in the Home Counties is now 27*s.* per 280 lbs.' The principle is the same, but, as in many other cases, we have witnessed a

substitution of independent and unbiased bodies by combinations of almost monopolistic trade interests.

In the legislation of 1918 and 1925, which prevented any material increase in the level of tithe payments, there is ample evidence that the popular agitation which had been successful in securing the passage of the Commutation Act of 1836 was still alive, and exactly a century later, there was placed upon the Statute-book another far-reaching measure to modify the incidence of this charge. In passing, may I point out that if recently, in order to control tithe disputants, extraneous police detachments were sent to Kent, in the early nineteenth century troops were being dispatched to that same county, where 'the disturbances (on the part of the agricultural labourers) have now attained to almost alarming magnitude. Each day brings fresh accounts of violence and outrage, and fear and excitement everywhere prevail' (*The Times*).

Yet again, the Reform Act of 1832 had its correspondingly expanded successor in our Representation of the People Act; both, by enlarging the field of responsibility, reflect the same psychological reaction to times of stress. The legal treatment of the rural workless had, after twenty years of misery and even of bloodshed, been mercifully metamorphosed by the 1834 Poor Law Amendment Act, the principles of which survived until a few years ago, when, once again, the recurrent twin problems of unemployment and the inequitable distribution of the resultant charges forced the State to recast the whole system in various Acts of Parliament, ranging from reconstitution of Local Government to extended provision for social insurance.

This chronological analogy could be further extended by effecting comparison between the crude protective duties current for a generation after 1815, and their ostensibly revenue-producing successors of recent years. Sugar-beet may illustrate the continuity of international agrarian history, for, although the Germans could claim priority in this field, it was as a result of our blockade of France that the crop was first subsidized and commercially

developed by that country; while the former nation's submarine threat led to our adoption of a like policy in the Great War.

It is, indeed, only when one turns to the human element—and then especially in its capacity as an employee—that this remarkable series of analogies breaks down, for a century ago the evils associated with the prevalent system of rural employment are epitomized in such words as 'Tolpuddle', 'Swing', and in many another place- or family-name, while the then customary and legal relationship subsisting between landlord and tenant would scarcely be credited by the present-day representatives of either body. Listen to 'The Thunderer's' views upon the first stirring of agrarian Trade-unionism.

'The public, we believe, are not aware of one subject with which the Cabinet has been occupied at its recent meetings; and when they come to hear it, those who watch political symptoms will confess that one of a more truly portentous character has seldom offered itself to the attention of this or any other Government: we mean *the spirit which has for some time directed the combinations of the working classes* against their employers. If this spirit proceeds as it threatens, we give it as our well-weighed opinion, that neither lawful authority nor private property (as for commerce and manufactures, they are out of the question) will be worth as much as five years' purchase from the date at which we are writing' (September 30, 1825).

Here we do, indeed, find an altered outlook, for the Agricultural Wages Boards, the logical corollary of Trade-unionism, have eventually been supported by all political parties.

Can I better illustrate the changes wrought by the passage of those five-score years than by enumerating some infractions of the law for which participants in agriculture could then and now suffer fine or imprisonment? *Then*, these penalties faced the worker who, with two or three of his fellows, 'combined' for the purpose of seeking an increase in his rate of remuneration; *now*, punishment awaits the employer who fails to pay an independently determined minimum wage. *Then*, retailers who sold

bread above the standard price fell foul of the law; *now*, producers vending commodities (e.g. milk) below a stated price suffer collectively administered financial retribution, as also do those who dare to raise more than an arbitrary acreage of certain crops (e.g. potatoes), whilst only a predetermined minority has effective access to some others (viz. hops). Take other fields for comparison. *Then*, forestalling and regrating, although absolved from any legal stigma, were still looked upon askance as potential dangers to trade; *now*, their practice forms, in effect, the recognized livelihood of large sections of the community. *Then*, landlords were omnipotent; *now*, fortified by Agricultural Holdings Acts innumerable, the tenant can virtually dictate his terms to a subservient owner. In the 1820's and the 1830's the tenant-farmer as well as the landowner staggered under the weight of National taxation, while together they had also to meet special duties upon a multiplicity of capital and productive goods—e.g. cart- and saddle-horses, gigs and traps, the malt they produced—and they had also to contribute, without any special concessions, to the unmodified demands of the rate-collector at a time when, even in rural areas, local taxation could exceed 20*s*. or 30*s*. in the pound, and they were, literally, tithed in kind. *Now*, as I shall hope to demonstrate later, the emasculated charges that remain can be laughed at by those men's great-grandsons. To illustrate, however, in passing, to what a small extent the vast remission of taxation is appreciated by these interests, I recall how, a few years ago, a meeting of East Anglian farmers passed with acclamation a resolution protesting against the weight of taxation that then crushed their industry. Their surprise was great when informed that the same resolution had been originally adopted in the same county exactly a century earlier.

When summarizing the results of the policy followed during the post-Napoleonic war era, it is significant to observe that its cost to the Exchequer was negligible, for, rock-like, it rested on the axioms that consumers should pay to the utmost (in order that tenants and landlords

might be re-established in secure positions), and that workers must, for the sins and omissions of statesmen, unavoidably suffer in full the blasts of an economic hurricane. A hundred years ago there emerged no measures aiming at the rehabilitation of agriculture that could incommode the taxpayer, and, if we exclude the reliefs granted to the rural poor, none affected the ratepayer. Nor, in consequence, did any real change in the practical side of the industry reveal itself. War-expanded cereal acreages were, for the time being, required to meet the Malthus-defying trend of population; and in the county of Norfolk, on Lord Leicester's and other reclaimed marshes, the bullock, where once the bittern had boomed, could, it was claimed, still batten, but not necessarily with profit to its owner. The inevitable emergence of Free Trade was, as a result of the hostility engendered by the Act of 1815 and its successors of the twenties, possibly antedated by a decade.

Such, from the landowner's and the farmer's standpoints, were then the results of two decades of European war. The worker, thanks to a compulsory and biased system of inclosure and also to the loss of extraneous sources of family income—attributable to what is popularly known as the Industrial Revolution—found his resources permanently crippled and his, often hereditary, association with the land dissolved. The Nation, whilst recognizing no obligation as resting upon itself, could, during the next generation, watch with equanimity the astonishing march of bricks and mortar across the northern face of England's 'green and pleasant land'—and also, incidentally, outwards from London across its brown and fertile arable fields. By an almost unbelievable piece of parsimony the only official connexion between the State and agriculture had been severed when the old Board of Agriculture, formed under stress of war and in recognition of Arthur Young's unique services, failed by little more than two years to survive his retirement in 1820. Its resurrection, oddly enough, occurred during a time of high farming, and when depression was a thing of the

past, with the establishment, in 1865, of a branch of the Privy Council charged with the control of animal diseases.

The vast changes in a century revealed by such a synthesis must, if the causes are sought, be placed in two categories. On the one hand, those improvements in the relationship of master and man, that strengthening of the position of the tenant at the expense of the landlord, the great amelioration in the social life of all those who labour on the land—these are attributable to a steady and continuous readjustment of standards, without regard to any fluctuations in the state of agriculture itself, which have equally affected other industries and the rest of the community, and have not resulted from any *ad hoc* expenditure upon the country-side. On the other hand, all changes improving the financial stability of the industry, reliefs of a fiscal character, all complementary economic adjustments, synchronous with each successful attempt to improve the material and technical equipment of the farmer, can be progressively correlated with recovery from the last two periods of depression, and obviously indicate a growing sense of responsibility, not perhaps invariably altruistic in character, towards an undertaking which had been for too long the Nation's creditor.

The first of what may be termed the two modern agricultural (and general) depressions that followed upon a generation-long period of unexpected prosperity, due to monetary causes which more than countered the incidence of Free Trade and its accompanying policy of *laisser-faire*, I need not describe, for the effects produced in the eighties and nineties, especially upon the arable districts, are familiar to all and remembered by many. The predominant cause was a world disparity between the demand for, and the supply of, gold which had brought about an average fall in commodity prices of 40 per cent.; subsidiary causes were the rapid growth of overseas competition and a series of climatic vicissitudes. On that occasion, despite the recommendations of numerous witnesses before the Royal Commission of 1894, which ranged from suggestions for the adoption of bimetallism to the

reintroduction of import duties, it is noteworthy that remedial measures were practically confined to reliefs from taxation. The rates on agricultural land, representing at that time only some 2*s.* to 2*s.* 6*d.* per acre, or less than 2 per cent. of outgoings, were halved by the Agricultural Rates Act of 1896; payment of tithe was legally shifted from tenant to landlord, and the maximum incidence of Land Tax was reduced from 4*s.* to 1*s.* in the pound. The total cost of the first and last of these measures was less than £1½ million per annum, for the Treasury had agreed to meet only the then existing half-share of the produce of rates on farmed land (£1,320,000) so that thereafter the taxpayer could with equanimity view the rising poundage —not so other contributors. The Nation, as represented by its publicly uttered or published opinion, and the administration were content to leave the trinity of British agriculturists to find its own solution. True, the housing, education, and health of rural workers were now the subject of State intervention, but these were matters of general application and represented no special solicitude towards agriculture. Hours and conditions of labour remained, in this industry, unregulated. The farm was not yet a factory; still less was it a controlled unit of production. It is perhaps a legitimate claim to make that the initiation, in 1866, of seemingly so unimportant a matter as the collection of agricultural statistics formed the real foundation-stone of that structure—a Ministry—which was progressively to foster, and to direct, the farmer. Certainly, for the first time, there was thereafter available basic information relating to the then position and the future potentialities of British agriculture.

Although no farmer of the nineties would have dreamed of giving vent to the apocryphal cry of his grandfather, 'What we want is another war', yet, had he but known it, nothing but such a catastrophe would have moved any administration to succour his industry. Actual hostilities with their terrible aftermath of general unemployment, overtaxation, debt, deflation, and psychological *sequelae*, are clearly pre-requisites to any determined efforts to help

our paramount industry. But, in the nineties, no foreigner threatened us, our secondary products were freely exchanged for an abundance of cheap food obtained from the ends of the earth, few statesmen worried over the loss of some millions of acres of arable land or the emigration of a few hundred thousand agricultural workers. Left to fight, by their own resources, an economic blizzard, the farmers spontaneously developed such new forms of their industry as the long-distance milk trade and the production of fruit, vegetables, and other foodstuffs of a luxury character which the growing wealth of the country could command; the meat trade, at first a standby when cereal prices sagged, was latterly wellnigh overwhelmed by overseas competition. Providentially, foresight and determination at home were supplemented abroad by application of the cyanide process to the extraction of gold and the proved ability of native races to endure life at a depth of more than a mile below the earth's surface when winning this economic prophylactic. World prices moved responsively upwards, carrying with them those of British agricultural products, and recovery was well on its way by 1908.

At that time, too, the State tentatively assumed certain additional responsibilities; by strengthening the powers of the Board of Agriculture; by legislating—it must be admitted, abortively, in the first instance—for the provision of smallholdings; and in certain other ways that would now be dismissed as parochial, but which were, at the time in question, the subject of astonished comment. Again, however, the cost was low—in keeping, indeed, with canons sacred to Gladstonian finance—and it might, for instance, be claimed that technical instruction to the farmer owes its inception to an unexpected windfall of 'whisky-money' rather than to any predetermined Government policy of succour. So passed away, almost imperceptibly, the second great period of rural depression in these Islands, and it did so without affecting either the national outlook or the national purse.

Any commentary upon the years 1914–19, with their

story of rigid control applied to every feature of the industry, is fortunately not called for, nor am I here concerned with the gigantic cost of that control to the State, for my real objective is the third great period of agricultural depression—that which, starting in 1922, is, with most of its problems, still facing us. As I have already stressed its causatory and fundamental resemblance to that regnant from 1815 to 1830, I can pass on to analyse and to evaluate the remedial measures that have emerged, for, in contradistinction to previous experience, we may now claim that peace hath her subsidies no less diverse than war. The sixteen years in question can be divided into two distinct periods—the first productive of direct subsidies, grants-in-aid and reliefs from taxation; the second marked by an entirely new development, i.e. the attempted control both of home production and of importation, accompanied by the re-establishment, after eighty-six years, of fiscal duties.

I might perhaps at this stage be expected to assess the weight of this depression and to effect comparison between it and its two predecessors. For various reasons, however, I will confine myself to the following brief statements. British agriculture does not form one industry, but is, in reality, composed of many, and depression has rarely weighed with equal severity upon all of them simultaneously; in general, the arable districts have suffered longest and heaviest, and in proportion to the weight of their soil; war profits carried many farmers well into the lean years; it was only in 1931 that agricultural bankruptcies equalled the level attained in the nineties (when at most one in five hundred farmers failed annually); new products, and the expansion of the more remunerative older ones, frequently brought help where it was most needed; the economic situation of the landowner has declined even more than that of the tenant; while, justifiably, the standard of living of the worker is now greatly superior to what it was in 1914.

In approaching my main thesis I propose, before attempting to estimate the results accruing from the policy

each represents, to enumerate, and, as far as possible, to assess the total cost to the State of the various reliefs and disbursements of an eleemosynary character that these post-War years have witnessed. I do not apologize for this, as I feel confident that a large majority even of the agricultural community does not appreciate the weight or the diversity of these aids.

First must be placed the direct, recurrent and non-recurrent, grants. Chronologically, in the forefront of the former comes the Corn Production Acts (Repeal) Act, which, in 1921, resulted in the payment of over £18 million to the growers of wheat and oats in Great Britain. By this means some three-quarters of all the occupiers of agricultural land received £3 and £4 per acre respectively, or an average of about £80 per head, for the crops in question raised that year. Additionally, a further million pounds was deflected to the furtherance of rural education and research.

The subsidizing of sugar and molasses derived from home-grown beet—nowadays a much discussed product—has, with the perfectly legitimate inclusion of the concurrent Excise remissions, during the thirteen years of its existence cost the taxpayer just under £58 million. At this stage I will not comment upon the very debatable economic repercussions affecting sugar refiners, foreign cane and beet producers, British shipping interests, or home road and rail services. The benefits derived from the introduction of this crop into our farming economy have been undeniably great, but the spectacle of two hemispheres subsidized to compete for an overstocked market is a remarkable one.

The redemption of a solemn war-time undertaking to settle ex-Service applicants upon smallholdings caused the expenditure, through the medium of the County Councils, of £15,250,000. The precise cost to the State of establishing the 17,000 persons in question is extraordinarily difficult to assess, but I am indebted to friends at the Ministry of Agriculture for the following information. Some nine-tenths of the sum was advanced by the

Public Works Loan Commissioners, and the high rate of interest on post-War borrowings, coupled with an abnormal cost of equipment, accounts for the resultant excess of annual expenditure over annual income. This long-term commitment will, by the final year, 2003, have aggregated some £40 million. As the Ministry is in reality paying interest, but not the charges upon the loan, the over-all average annual deficiency payment will be £565,000, equivalent to £34 for each smallholder. At the present time the charge is some £800,000 per annum —in 1950 it will be £700,000. The weight of such protracted liabilities, both from the national and the personal aspect, is apt to be overlooked, and, remembering the economic hardships to be faced, it is perhaps fortunate that less than half the would-be settlers waited for land.

The Forestry Commission will, under two separate programmes, have expended in eighteen years just under £8 million. This is, in effect, a variant form of long-term subvention that will one day begin to yield substantial returns as the Commission's properties become commercially remunerative.

The cattle and milk subsidies officially represent in part contingent liabilities which are to form claims upon any levies that may hereafter be collected upon imported meat and upon the future resources of the Milk Marketing Board. Even, however, if we accept as certain such repayments, there remain non-returnable State contributions, amounting in the years 1934–5 to 1937–8 to £4,600,000, designed to improve the quality of milk, to provide for its sale at reduced rates to schools, and to assist in the production of manufactured grades. During the four years ending September 1938, £15,923,000 was spent on the beef subsidy, which has averaged about £325,000 a month.

The various post-War measures by which credit has been made more freely available to the industry have caused what would, in normal times, have been regarded as heavy expenditure. Under the Agricultural Credits Act of 1928, a State subscription of £10,000 per annum was guaranteed to the Agricultural Mortgage Corporation,

and this piece of legislation, together with the previous Trade Facilities Act, has led to the granting of long-term loans exceeding £12 million in amount.

While it was implicit in the Wheat (Quota) Act that no expense should fall upon the Exchequer, the corollary of an enhanced price for British wheat now calls for annual charges up to £8 million, and it is clear that the 'deficiency payments' themselves have, on occasion, been worth to the producer somewhat in excess of £4 per acre of wheat. If the whole charge is deflected to the wheat-eater—which it is claimed is demonstrably not the case—the extra expenditure per household can be in the neighbourhood of 15*s.* per annum or 3½*d.* per week.

It is with the greatest diffidence and hesitation that I countenance the possibility of combining under one head these recurrent or terminally fixed payments, for they vary so greatly in their characteristics and in the relative exactitude with which they can be assessed, but I may hazard the suggestion that, to the *taxpayer*, their gross weight, exclusive, of course, of the 'wheat deficiency payments', has during the last eighteen years exceeded £120 million or an average of £6,700,000 per annum—say 5*s.* for every acre of crops and grass in England and Wales: a very disproportionate share has, however, rightly been deflected to the arable districts. As will be indicated shortly, the actual sums expended in recent years, owing to the incidence of meat and milk grants, have been nearly twice this over-all average.

Next come the annual State disbursements of ever-widening range, made through the medium of official and semi-official bodies, that represent an aggregate sum which would, in pre-War years, have elicited astonishment. Owing to the number of different heads under which the relevant votes fall, it is extremely difficult to determine the total sum thus expended, but at the present time it clearly exceeds £2,500,000 per annum, and ranges from capital grants for building extensions to the establishment of teaching posts and the provision of a complete system of agricultural scholarships, while, too, whether directed

to the Outer Isles of Scotland or to the English countryside, it ameliorates the life of the peasant.

The addition of the last-mentioned item will, in such a year as the last, bring the grand total of current *payments* —again, exclusive of 'wheat deficiency grants'—to over £15 million per annum, which large sum it must, however, be admitted, represents less than 2 per cent. of the Nation's Budget. In 1913–14 the amount corresponding to the above-mentioned £2,500,000 was £900,000, which, like it, was expended through the Board of Agriculture, the Scottish Department of Agriculture, and the Development Commission. Drawn from a budgetary expenditure of less than £200 million this figure is not only widely but fantastically disparate to that recorded above, and apart from the de-rating contribution, it represented the then total national outlay upon the industry.

In view of the fact that grants-in-aid may, from the standpoint of recipients, be very different from that of the taxpayer, it will naturally be asked what proportion of the above financial assistance has reached those actually engaged in farming operations. The answer would appear to be as follows. The whole of the wheat and oats subsidy of 1921 was received by cultivators, as are now the 'deficiency payments' under the Wheat Quota Act, which, with scarcely any loss, balance the 'quota' charges on flour. The sugar-beet subvention presents an extremely difficult problem, which the Greene Committee of Inquiry avoided answering beyond saying that, in 1934–5, its *cost* was equal to £17 an acre. While boldly venturing into this controversial field, I should perhaps first refer to the suggestion, sometimes made, that, with an average net cost of production—always extremely difficult to determine—of some £13 or £14 per acre and cash receipts of £19 per acre (on a beet price of £2 per ton), the factories would, in the event of the subsidy being withdrawn, increase their contribution to the price from £2 to £4 per acre and that, therefore, the gross value of this assistance can be reckoned as high as £15 per acre. A second possible method of evaluation rests upon the assumption

that the difference between the cost of production and the average return of £19 represents the subsidy's value. Such a differential would be some £5 or £6 per acre (including the value of by-products)—which, of course, excludes any advantage derived by the worker owing to enhanced wages. Yet another theory, strongly Protectionist in character, insists that, in effect, the home producer is not being subsidized at all until his rates of benefit exceed those provided for his most favoured Imperial competitors; this basis would give a value of £6 per acre. To me it seems plausible to hazard the suggestion that, despite various difficulties associated with rates of exchange, the fairest method is to attempt to locate the difference between the average of world beet prices and of those ruling domestically. A few years ago, when the world value was 25*s.* per ton, compared with 40*s.* for the internal price, there was a difference of 15*s.*, or, with a yield of 9·5 tons, of £7 per acre. Incidentally, all the methods enumerated above, except the first, give results that correspond closely with the widely spread empirical belief that one-third of the gross State expenditure has reached the farmer and his employees. The sugar-beet subvention to-day represents the sum paid to the manufacturers to reimburse them for their payments to farmers above the figure which would make it possible for them to make a reasonable return on their capital. Last year this amounted to £1,274,000, and it must be assumed that this represents the benefit accruing to growers.

It is obvious that, on beef, the variable subsidy per live cwt., averaging approximately £2. 15*s.* per beast, represents a clear addition to the impossibly low prices that would otherwise have been secured; the failure of an anticipated rise in prices led, incorrectly, to the claim that middlemen had absorbed these grants. Admittedly, the consumer is paying more for his milk, and the distributor is enjoying no smaller margin, while in this trade the producer can point to a guaranteed outlet rather than to substantially enhanced prices as the principal result. Sums devoted to afforestation, the provision of smallholdings,

and to a certain extent, sugar-beet, have percolated to many grades of cultivators—actual or potential—but a small proportion has doubtless remained with owners, who find land values improved thereby, while certain ancillary trades, e.g. transport and building construction, have been provided with augmented outlets. Few of the grants have failed to provide additional employment or at least to prevent diminution in the numbers of wage-earners.

Payments under the Agriculture Act, 1937, have certainly not yet reached their maximum. Farmers were quick to take advantage, however, of the Land Fertility Scheme, more than £1,600,000 being paid, in the first year, by the Exchequer to subsidize the purchase of lime and basic slag. Subsidies to oats and barley growers amounted to £164,000.

When one turns to investigate the truly remarkable reliefs from the 'burdens'—both statutory and non-statutory —which have been implemented during the last fifteen or sixteen years, one finds tax-, rate-, and tithe-payer all affected. By the Agricultural Rates Act of 1923, which halved the contribution of agricultural land (already, under the provisions of the 1896 Act, reduced by 50 per cent.), the Exchequer thereafter handed over to the local authorities of Great Britain an annual sum exceeding £3,800,000; this, of course, was in addition to the £1,320,000 per annum falling due under the Act of 1896. In 1925 the derating of agricultural buildings necessitated a further contribution, amounting to £700,000 per annum. In 1928 the remaining quarter of local taxation falling upon land, representing £4,132,000, was remitted. The occupiers of agricultural land and buildings in England and Wales alone have, by these means, been relieved of payments which would, in recent years, prior to the readjustment of the Block Grant system, have amounted to about £16 million per annum, equivalent to an average of 12*s.* per acre; rather more than half (£9 million) of this sum must have been derived from the pockets of the taxpayer, the bulk of the remainder being charged upon non-agricultural ratepayers. It may be recorded that this relief

represents some £40 per 'average' holding, or £50 per occupier per annum. Similar remissions and reliefs have been accorded in Ireland where, in the case of the Free State, it has been calculated that payments from farmers have been reduced to £2 million per annum; in Scotland £800,000 has been remitted to landlords and £150,000 to tenants.

Even taking into consideration the recent slight fall in the poundage of local rates, it is true to say that, in the aggregate, reliefs from rating must, in Great Britain, represent some £17 million per annum. Whatever theory may postulate, or particular interests suggest, there is now no evidence, any more than on previous occasions, that as rates were remitted agricultural rents rose, so the full concessions have been enjoyed by their intended beneficiaries.

Rightly classified as a 'productive industry' under the general derating scheme, agriculture secured a yet further concession, assessed at £800,000 per annum, in the shape of preferential rates for rail transport applicable to certain types of produce.

Finally, in approaching the vexed topic of tithe, all interests will perhaps allow me to state that, by the legislation of 1918 and 1925, landowners have been relieved of payments which, had this charge been permitted to pursue the course dictated by the then existing legislation, would up to 1935 have involved them in an additional contribution of £11 million. Under the Act of 1936, on the contrary, landowners have been relieved of the payment of nearly half a million per annum of the amount provided by the settlement of 1925.

Having now enumerated the principal *ad hoc* payments and remissions secured by British agriculture, and attempted to indicate their ultimate distribution as well as their cost to the nation, it is only reasonable that I should refer to certain factors, State-dictated, that figure upon the other side of the rural balance-sheet. The first of these was the re-establishment of the statutory Wages Boards, which, by raising rates of remuneration above the level

existing prior to 1924 (under the voluntary system of Conciliation Committees) to the extent of 6*s.* to 7*s.* per week, caused an addition of £16 million to the annual cost of labour in England and Wales (itself representing one-third of all outgoings) which in turn is equivalent to some 12*s.* per acre over all and may, in the arable districts, easily exceed 15*s.* per acre. Real wages, due to a steady fall in the cost of living, synchronously advanced. Secondly, our (as it proved to be) premature return to the Gold Standard in 1925, by raising the value of the sovereign some 5 per cent., also, for a period, militated to the extent of another 10*s.* per acre against the farmers' returns; it is fair, however, to point out that in its incidence it was not peculiar to the industry under discussion.

Ignoring for the moment any consideration of the financial advantages derived from import duties or from the avowedly price-raising quantitative control of home-produced and imported commodities, it is now possible to strike a general balance based on the principal foregoing items in their reaction upon the *producer*. In 1937–8, it reads, for Great Britain, approximately as follows:

	Credit £	*Debit* £
Wheat deficiency payments . .	1,933,000[1]	
Sugar-beet subsidy (including remission of duty)	3,377,000[1]	
Meat subsidy	3,943,000	
Milk grants	695,000	
Small-holdings and allotments . .	1,065,000	
Afforestation	800,000	
Ministry of Agriculture, Scottish Department, and Development Commission	2,667,000	
Local taxation reliefs. . . .	17,000,000	
Oats and Barley Subsidy . . .	164,000	
Land Fertility Scheme . . .	1,671,000	
Wages Boards		16,000,000
Net gain	17,315,000	

[1] The wheat and sugar payments for 1937–8 were exceptionally low owing to relatively high world prices; for 1938–9 the wheat deficiency payments are estimated at £8 million.

In reviewing these figures, it must be remembered that the official index-number applicable to agricultural commodities produced at home now stands at 30 to 35 per cent. above the 1911–13 parity, while with labour costing double what it did in 1914, and the price of feeding-stuffs 20 per cent. dearer and fertilizers slightly cheaper, the weighted average cost of production lies in the region of 50 per cent. above the 1911–13 level. The margin to be bridged, therefore, exceeds several times over the credit balance revealed above, which, in round figures, may be taken as equivalent to almost 15*s*. an acre.

While taking care not to impinge seriously upon the more practical aspects of the question, it will perhaps be appropriate if I illustrate by local example, derived from such a typical arable area as Norfolk, the results of State assistance. This is the soil which, in ancient times, according to that great Norwich medico-antiquary, Sir Thomas Browne, protected certain 'minor monuments from the drums and tramplings of three conquests'. It has subsequently had to endure a similar number of economic assaults upon its own productivity.

Here, in 1937, the 975,000 acres of farmed land derived, in round figures, the following major pecuniary advantages: 'wheat deficiency payments' (calculated on the Wheat Commission's official basis of 1*s*. 7*d*. per cwt.), £147,000 or £1. 5*s*. for every acre grown; next year it is certain to amount to over 4*s*. per cwt. or £400,000. Rating reliefs (at 13*s*. in the pound on agricultural land and buildings), £634,000; the sugar-beet subsidy brought in from £600,000 to £800,000. Under the Agriculture Act, 1937, the subsidy on lime and basic slag amounted to £23,500, and on oats and barley to £27,000. The meat subsidy, together with the grants directed towards education, smallholdings, afforestation, and so forth, must have amounted to at least £300,000 or 6*s*. per acre. We arrive, then, at a possible total of £1,900,000, say £1. 19*s*. for every acre in agricultural utilization. From this must be deducted over £500,000, or 11*s*. per acre, as a result of the increased rates of remuneration ordained by the Wages Board,

leaving a net gain of 28*s*. It is a curious coincidence that sugar-beet benefits and wage increments should nearly cancel one another out, for it has been repeatedly claimed by East Anglian farmers that the former were entirely absorbed by the imposed higher cost of labour.

When it is borne in mind that the over-all per acre value of our soil products is barely £9, and that it must cost £7 to raise an acre of wheat, £4. 10*s*. an acre of seeds hay, and £25 an acre of potatoes, the advantages derived are, if not striking, at least appreciable. Statistically, the resultant changes in Norfolk agriculture are not unexpected. Wheat is now back to its pre-War acreage, while (regulated) potatoes and the fruit areas have increased; the other cereals have declined, while sugar-beet has largely supplanted turnips and mangolds. Milch cattle are now more than 50 per cent. above their pre-War numbers, the sheep population is only two-thirds of what it was, but pigs, beneficiaries under the new régime, have increased by 75 per cent. The arable land has not been reduced disproportionately to the national loss attributable to the demands of a more mobile and discriminating urban population. It is probable that increased mechanization as much as financially dictated staff reductions has been responsible for the withdrawal of some four thousand whole-time male employees during these eighteen post-War years.

Norfolk may, indeed, be taken as illustrative of the recent post-War tendencies exhibited by the country as a whole, and frequently unappreciated by the man in the (urban) street. They are as follows: a slight increase in the physical output of the soil, a decline in arable area, which would undoubtedly have been much larger but for the grants-in-aid directed to specific crops; a marked transference from the production of feedingstuffs to that of sale crops; a reduction in the number of workers, accompanied by a greater output per person employed; and a redistribution between the different classes of live stock, which still accounts for three-quarters of the total agricultural output expressed in terms of money. Nationally, there has occurred a very marked augmentation in the

consumption of Imperial as opposed to non-Imperial supplies, together with an increase in the *per caput* consumption of the more expensive foods.

Of the expenditure which has brought about these results, landowners, have, directly, received little, and their position has, owing to permanently enhanced costs of maintenance and repairs, continued to deteriorate. Tenant-farmers have, by it, been enabled partly to bridge the gap that would otherwise have rendered them impotent to function as producers. The economic betterment of rural workers can best be measured by recording that in 1938–9 their weekly wages stand at nearly 100 per cent. above the pre-War level, while the cost-of-living index-number remains in the region of 50. Remembering the immovable attitude of the administration, and also the public apathy, of forty to fifty years ago, and knowing the terrible situation that faced their predecessors yet a century earlier, the present representatives of what is justly one of the most famous agricultural counties in England must surely feel encouraged by these tangible signs of support to continue their efforts to escape from the darkness of depression into the light of returning prosperity.

Let us now leave the subject of direct financial impacts and benefits, resultant upon State action, to be weighed according to individual opinion, and consider the repercussions attributable to higher policy which involve economic and fiscal adjustments often extraneous in character. The precursors of marketing reform on the grand scale emerged in the shape of the Horticultural Produce Act of 1926 and the 'Rings' Act of 1927 (both of which attempted to strengthen the position of the farmer in regard to the sale of his produce), extension of the C.O.D. system, and the setting up of the 'National Mark'—all these supplemented the Empire Marketing Board's policy of concentration upon the business functions of the producer. The cost of that Board during its short life (at first a million per annum, subsequently reduced to half that figure) was small compared with the incipient value of its

work, which clearly paved the way for the far more ambitious operations of the Agricultural Marketing Acts. By the latter legislation our internal policy was completely altered, and overriding powers were conferred upon proved majorities to transfer, withhold, process, or otherwise dispose of, 'regulated products' in order to control output, with the economic *suggestio falsi* that, if fully successful, such a price-raising system would merely readjust profit margins between farmers and intermediaries without raising prices to consumers. When, however, it became apparent that unrestricted supplies from overseas were effectively paralysing the original (1931) Marketing Act, its successor was passed which gave to the Board of Trade full powers quantitatively to control imports of any agricultural commodities already subject to the provisions of the former Act.

The delicate 'gentlemen's' (but not necessarily economists') agreements, soon sought with the Scandinavian group of countries and with certain South American producers, in the hope that their exports might be cut down to the required figures—generally expressed as percentages (*c.* 60–90) of some basic year or average of years—were not always easy to conclude. Trade agreements or Ottawa pledges have prevented or delayed, in the case of certain articles—e.g. milk, meat, and dairy produce—the introduction of such undertakings with some foreign countries and with several of our own Dominions and Dependencies. With import duties also imposed, in 1932, upon a majority of agricultural and horticultural commodities, including one on foreign wheat at 2*s.* per 480 lb., and 10 per cent. *ad valorem* on foreign flour, our Free Trade principles, jealously guarded since 1846, were jettisoned and 'the people's food' was taxed indeed.

It is extremely difficult to estimate in terms of money the net results of a 'planned' agriculture at home, combined with reduced non-Imperial imports. Commodities sold off farms were valued at £222 million in 1932–3, and in the latter year the index figure of prices was 107. During 1937–8 they have averaged some 20 per cent.

above the level of 1932 and 1933. This, for Great Britain, is equivalent to an aggregate rise in producers' receipts of £40 million to £45 million. If we feel justified in ascribing the whole of the officially recorded increase to the influence of the Marketing Acts and their supplementary legislation, this is the sum that must be added to the grand net total, £17,315,000, of subsidies and reliefs previously enumerated, for the new policy is supplementary to the old—based on long-term grants—which of course continues side by side with it. We thus arrive at a figure approaching £60 million as representing the cumulative annual benefits derived from the three policies, viz. grants, remissions, and augmented prices. The increase in prices, however, has been due partly to increased industrial prosperity. The new method is far more potent than the old, and, although it is arguable to what extent, if any, middlemen's returns have been affected, it concerns most intimately the consumer. The direct taxpayer, it should be emphasized, has thereby gained a measure of respite at the expense of the indirect.

Including these price- and quantitative-control devices, the home market is now in possession of an almost complete battery of economic weapons. During the period 1932–8, the result has been seen in a rise in the wholesale prices of its products of 20 per cent., accompanied by a considerable increase in the proportions of Empire, at the expense of foreign, consignments. This has been accomplished at the cost of a growing dependence upon outside direction and some expansion in the numbers of persons ancillary to the industry. Forms to be completed, contracts to be signed, instructions to be obeyed, inspections to be suffered—these are the penalties of a planned and a regimented industry.

The demand for potatoes as human food is, to a certain degree, elastic, and the Boards have it in their power, by withdrawing small varieties, to raise the price of those in other categories; acreage restrictions should then prevent any tendency to over-production. Potato prices, whilst not soaring, have substantiated economic theory, while heavy

duties on imported 'earlies' have buttressed the whole structure.

The milk industry has perforce become accustomed to receiving, through eleven 'pools', payments calculated in pence per gallon to two places of decimals, and varying with the status of the producer, the season, the locality, and the intended utilization of individual consignments; many producers and a larger proportion of consumers remain in ignorance of the destination and of the source respectively of a commodity whose production and handling are vital to health. Significantly, no provisions for limiting output have at present been imposed, and the Board's energies have mainly been devoted to increasing the consumption of fresh milk at the expense of that unremuneratively disposed of for manufacturing purposes, while the average pool price secured by producers rose from 11·8*d.* per gallon in 1933–4 to 12·0*d.* in 1936–7 and 12·9*d.* in 1937–8.

Producers responded too well when first invited to contract for the supply of high-grade bacon pigs, and, if prices were to be maintained, limitation of supplies was essential. When faced with markedly higher retail prices consumers became restive, there was evidence that demand was shifting to alternative commodities, and simultaneously the European exporter expressed open dissatisfaction with his reduced opportunities. Another policy, announced in June 1935, was not adopted, and a subsequent alteration was announced in July 1937. At first a levy raised on foreign bacon imports was suggested as a means of augmenting the price of pigs at home, but this was subsequently abandoned in favour of a direct subsidy from the Exchequer.

Certain branches of the industry, such as fruit, vegetables, and poultry, have rejected regulating schemes, preferring, presumably, to trust, in conjunction with specially granted fiscal protection, to those insular advantages that they possess.

British agriculturists, having witnessed for long the evils of neglect and *laissez-faire*, would have been foolish

to refuse, at any rate for a time, this form of assistance on the ground that it involved certain sacrifices on their own part, and, when looking around at other occupations, including those of their fellows in many different countries, were wise to accept compulsory co-operation. For, as with armaments, so with industry, it appears, unfortunately, at the moment to be the accepted rule, *si vis pacem bellum para*—if the primary producer wants enhanced prices and thereafter stability, he must seek both by outbidding in tariffs, subsidies, and exchange restrictions the aims of foreign countries. Agriculture will assuredly be the last industry spontaneously to support the reintroduction of Free Trade.

The passage of a hundred years has witnessed a vast change in the treatment of social and economic problems, and nowhere is this more marked than in agriculture, where solicitude has ousted severity and preferential treatment superseded *laissez-faire*. We see agriculturists throughout the world, white, yellow, brown, black, faced with the twin problems of apparent over-production and under-consumption. If analysed, however, the former generally appears to be due, in the main, not to technical improvements such as mechanization combined with higher rates of yield, but to State maintenance of artificially augmented crop areas by means of devices, often meretricious in character, designed to bolster up submarginal producers or those attracted to the industry by the lure of war-time price-levels. Equally, we observe many secondary industries in this and other countries struggling against reduced prices and augmented costs of production. Everywhere we see nationalism, elevated upon a pedestal, temporarily defying, with the aid of every device known to the wit of man, economic and financial vicissitudes, which in turn clog the transference of men, money, commodities, and services. We see European states fostering their peasantry by every artifice in order to secure agrarian tranquillity, and we see, simultaneously, the United States of America pouring out thousands of millions of dollars to improve the prospects of her more

extensively engaged producers. Everywhere the cry is 'More land for the People!' and 'More people for the land!'

Have we in this country not done wisely to pursue, during the latest of three onslaughts, a middle course (in relation to the above examples): on the one hand, not extravagant in money, nor, on the other, by persuading an undue proportion of our population to live on, or by, the land, subversive of ethical standards? Even such a policy as ours represents, however, a complete break with tradition and with outlook in regard to social as well as to economic matters, and it has been accomplished at first by comparatively heavy financial commitments, to be succeeded in turn by the adoption of a 'planned economy' that has called for readjustments in the respective interests of consumers, distributors, overseas producers, and even of other industries, some of which latter are themselves unsheltered from the blasts of world competition. This 'emergency' programme, as it was first termed, has been carried through at the cost of a reduction in the initiative and freedom of producers, by a certain transference from 'dirty boot' farming to the filling in of forms, by a progressive dependence upon outside authority, and, psychologically, by the growth of what may tend to become a defeatist attitude. Yet the appeal *non tali auxilio* has yet to issue in any volume from the lips of rural spokesmen. Up to the change of policy in 1932, the direct cost—even if we include those long-term commitments—had, by post-War standards, not been excessive, but the Nation, or, rather, the urban population, has now acquiesced in a policy which more and more affects not merely the producer and the taxpayer but every householder in the land, so that a price-raising objective has had to sustain criticism and inquiry from a far wider field.

I have refrained from discussing certain factors axiomatic to the new system, such as its effects upon our secondary industries hitherto engaged in exchanging their products for imported foodstuffs; the future trade and financial relationships likely to subsist between ourselves, our own Dominions, and foreign countries, as a result of

the restrictions imposed; and the political and economic risks attaching to any serious increase in the cost of urban living brought about by a virtually monopolistic and dominant rural hegemony. Upon these questions, that are of overwhelming importance and pregnant with danger, each must form his own conclusions. Fundamentally, too, the farmer whose production costs are high now secures recognition that formerly was the reward of his more efficient brethren. Nor can it be denied that this system of regulated production will, as a concomitant to increased profits for those permitted to remain, logically necessitate the exercise of restraint upon every soil product, including those essential to health, raised upon each commercial unit of land, which in turn must bring under review the determination of rent as well as (now) profits and wages. Whether justified or not on economic grounds, such a procedure would be open to attacks based on other, and wider, considerations, very difficult to counter. Even technically, a quota system has inherent disadvantages which render its stability uncertain and necessitate frequent revisions and adjustments to neutralize fluctuations in different sources of supply and in prices. Home producers prefer import duties to restriction, and we in this country must not forget that the latter method presents to our own kith and kin overseas a virtually insoluble problem in the shape of consequential control of their own individual producers.

It is therefore certain that the latest proposals, initiating a movement from quotas and levies to price insurance, with a modicum of Dominion preference, will meet with approval from both parties. During recent years we have travelled farther than in the whole of the previous century, and, perhaps kindly, 'the iniquity of oblivion has scattered her poppy', for we are in danger of forgetting to what an extent our rural and national economy has been transformed by official recognition of some of the abovementioned paradoxes.

It is said that 'a rolling stone gathers no moss', but may I suggest that if, in its third descent during a century into the valley of depression, British agriculture gained a

protective covering sufficiently effective to shield it from the worst economic shocks, in future this accretion may actually hamper it when progressing over the smoother and level terrain of normality that we hope lies in front of it? One is left wondering if the present system of 'reorganization' will survive any considerable passage of time, or whether, legislation having telescoped chronology, the comparatively near future may not witness, even as subsidies gave way to planned economy, some relaxation from control, some restoration of individual liberty of action, initiated, maybe, by nation-wide restoration of the gold standard giving greater freedom to world trade, and accompanied by the abolition of fear and avarice which would increase reciprocally the demand both for manufactured articles and primary commodities. One of the world's dictators has recently uttered the following dictum: 'What the situation calls for is the free movement of goods, of people, of capital, and of credit.' We, in these islands, have more to gain than any other nation by such a consummation.

Looking back on the past history of British agriculture, I am confident of one thing, that whether the time be far distant or near at hand, the industry will eventually resume its prosperity—its importance has never been lost—and unborn generations will regard the present epoch as affording one of those many trials through which, during countless generations, it has emerged unscathed but remodelled, this time not despite a policy of *laissez-faire*, but as a result of considered actions and preferential treatment of an all-embracing character meted out by the State with the approval of the majority of the nation.

AGRICULTURAL CONDITIONS AND POLICIES 1910–38

By A. W. Ashby

PRIOR to 1910 there were three main lines of social policy in relation to agriculture, all of them weak. Many farmers would have said there was no policy, while others would have said there was a policy of repression because of the withdrawal of the registration duty on wheat which was imposed at the beginning of the century and because of the absolute refusal of the nation to consider any policy of agricultural protection. There was a clearly marked policy of giving tenant farmers control of the cropping and use of land, with security for investments if not of tenure. There was also a thin and tentative policy of improving the conditions of farm labour, marked by provisions for allotments and smallholdings and by the extension to agriculture of the principles of employers' liability. There had been weak and uninspired efforts in the development of agricultural education, and small efforts in respect of research. In addition, there were the usual 'sanitary' activities to control diseases of animals and plants and 'police' activities to check fraud in the sale of agricultural requirements and fraudulent competition with the products of farming.

The 'big and little loaf' question was always liable to be important in General Elections, and was in fact important so late as 1910. People still lived who remembered as children the 'black' bread and the barley bread of the Corn Law days, and comparatively large numbers had vivid fears of food-shortage and of poor supplies from the stories told them by parents who themselves had suffered. The world as a whole was conscious of possibilities of famine. There had been recent famines in Russia and in India, and travellers from many countries brought and wrote tales of poor dietaries and half-starved peoples. The latest semi-famines of Great Britain and the United

States lay within the memory of parents of a living generation.

Yet a great change was preparing in the world at large, and what we now see as the third agrarian revolution was developing rapidly. The first began with turnips and clover, the four-course rotation, and the work of the early stock-breeders in the eighteenth century. The second began with the mechanical mower and reaper in the second quarter of the nineteenth century, and continued with the self-binder in the third quarter. Following the Franco-Prussian war, and with the increasing capacity of the towns to buy and eat animal products, there were considerable improvements in live stock, especially for meat production. At the end of the century, cheaper transport of grain completed the revolution as regards crop products, and refrigerated transport began to set up forces which entered into the third revolution.

The horse was still the friend of man and the cow had not ceased to be the enemy of woman. In the eighteenth and early nineteenth centuries, Britain had substituted horses for oxen in farm traction, but in many of the grain-growing areas of the world oxen were still busy. Yet the tractor was beginning to make its way towards American farms. Factory dairying had been practised in some areas for thirty years or more, but probably the bulk of the world's butter and cheese was still made on farms, and the whole-milk trade, as we now know it, was small in dimensions and local in character. The first agrarian revolution had permitted a great increase in population, the second vastly improved the dietaries of that population. Opening the new countries to agricultural settlement had caused great streams of migration of agricultural population, but with growing producing capacity of other industries and the equally expanding consuming powers of the general population the proportion of agriculturists in the total of occupied persons was falling continually in all the industrial countries. About 1913 there were people who said that prices of agricultural produce must rise, and agriculture must become prosperous, because the supply of

human labour in the industry was not more than equal to the production of the necessary supplies of food. There were even people who forecast shortage of food-supplies unless more people were attracted to agriculture. The tendency to reduction in rate of population growth had not been seen, and few people, perhaps, would have recognized any possibilities in this direction. Some were concerned with the growing dependence of Britain on oversea supplies of food, but there was common recognition of her peculiar position as an Imperial nation, most people were inclined to 'trust the Navy', a great many did not believe that war was unavoidable.

In these conditions, and just before the beginning of the third agrarian revolution, Great Britain began to develop her agricultural policy. The advent of Mr. Walter (now Viscount) Runciman at the Board (now the Ministry) of Agriculture marked the earliest appointment of a politician or statesman of first rank to its Presidency, and his administration showed a vigour of thought and action never previously seen in its offices. The creation of the Development Commission in 1910 marked the intention of the State to play a part in promoting the welfare of agriculture and rural life. A policy of creating small-holdings which had begun already was to be pressed forward. Co-operative enterprise in obtaining supplies or marketing farm produce was to be stimulated. Farmers' tenant-rights had been extended and strengthened in 1908, and so far as administration could strengthen them it would do so. Various special or new branches of production, such as flax, tobacco, sugar-beet, were to be tried, stimulated, assisted. Improvement of live stock was to be assisted by the supply of good-quality sires, and selection of productive and breeding stock was to be stimulated by assistance in making yield records. Most important of all, provision was made for a great advance in agricultural research and education. Research was expected to make sanitary regulations and protective work much more effective, and to some extent it was expected to extend the sphere of control of fraud. On the more positive side of

finding new materials, new or better-balanced combinations of materials, new methods, research was expected to accomplish still more. And in the field of the discovery of fundamental knowledge of plant and animal breeding and nutrition the possibilities were unmeasurable but promises were high.

No technical discussion of research is here intended, and only its economic effects will be considered. The emphasis was generally on increasing production. Although the more enlightened of agriculturists had in view possibilities of diminishing unit costs arising from results of investigations in the natural sciences, none of them apparently had begun to anticipate possibilities of regulating seasonal variations in yields and of regulating market supplies. Recognition of the new and yet largely untried science of agricultural economics was to bring a new factor into the set-up of agricultural science, and one which was not only to alter its scope but also to change its purposes.

Agricultural education was to be strengthened by increased grants to colleges and university departments of agriculture, the extension staffs employed by the county authorities were to be increased and strengthened, there was to be a link between county staffs and colleges and research institutes in the form of scientific advisory officers stationed at colleges and universities, and residential education for farmers was to be provided in farm institutes. Here again no technical discussion is intended, but it is necessary to complete the outline of the new economic and social forces which were being set up.

The general intention was to increase the technical and economic efficiency of the different branches of the agricultural industry. There were discussions of changes in its economic structure, but these were largely of academic character although not conducted wholly by people with academic connexions. Such discussions dealt with ownership *versus* tenancy, with suggestions of share-tenancy, or 'stock and land leases', with suggestions of the necessity or desirability of large-scale farming, with the advantages and disadvantages of smallholdings, and amongst these

the last was far the most important. A great many persons were concerned to establish an 'agricultural ladder' for both economic and social reasons, but the fact that this was made one of the chief bases of advocacy of smallholdings shows there were no expectations, no intentions, of making fundamental changes in the economic structure of the industry. Some such changes were to come as the unexpected results of other agricultural and social legislation.

Forces of technical and economic efficiency were to be set free and created; the agricultural labourer was to be given a chance in competition for the use of land. These were the main elements in the policy of the ruling party in the State and more or less of all the leaders of public opinion, although there were those with other ideas, especially of inducing the public to bear measures of protection in favour of agriculture.

But there were social reformers not content with the offers of allotments and smallholdings to farm workers, who were specially concerned with his conditions of housing, with the nutrition of his family, with his wages and earnings. Conditions of rural housing were beginning to affect the public conscience, but the people who wanted to regulate wages did not get much attention inside the industry. Resuscitation of trade-unionism had caused misgivings in some circles, hopes in others, but probably few of the leaders of the industry regarded it as either a permanent feature or a serious menace. The social ferments working round the position of the agricultural worker, however, were more active and potent than the industry recognized.

These were the conditions when War broke out; when the War set loose and strengthened forces which were to affect intimately the work, profits, and lives of farmers not only for its duration but up to the present time and probably for some years yet to come. Strangely enough, the War raised the hopes of agriculturists quite as much for changes in fundamental policy as for immediate prices and profits. Very soon there was agreement amongst

representatives of all parties that a change in policy was desirable, and by 1917 there was recommendation of guaranteed prices for wheat and oats, and a statutory minimum wage with a system of fixing higher variable minimum wages for farm workers. Perhaps no more rapid change of economic and social opinion had ever occurred in Great Britain than that towards agricultural prices and wages between August 1914 and January 1917.

Events, however, were to move more rapidly than social opinion. Prices quickly moved above the statutory minima fixed in 1917. Administrative opinion soon decided in favour of compulsory powers to secure increased production, and powers under the Defence of the Realm Act were used with energy if not always with discretion. Very soon it was found to be necessary to fix maximum prices for agricultural products rather than support them with guarantees. Methods of increasing production developed rapidly, from the application of research and education, to active forms of publicity and propaganda, next to financial inducement, and then to compulsion.

The most drastic and permanent changes in the industry were the reduction in the supply of labour, the increase in wage-rates, and the experience of wage-regulation and some conditions of labour. Where these may yet lead we do not know: they may make of the British a typical peasant system with a smaller number of hired workers than of occupiers and members of their families, for a considerable change in that direction has already occurred. They have also exercised considerable influence in obtaining for the industry such measures of protection as it now enjoys.

The idea and the policy of guaranteed prices have had a chequered history, but at the opening of 1939 they are coming back into prominence. Methods of obtaining and controlling imports of competing products during the War also began to affect general ideas of policy, at least Socialist policy, immediately afterwards, and since 1933 but particularly since 1936, in modified forms, they have

had widespread acceptance. Experience of sale of fat stock by grade was also useful at a later stage.

Principles of setting minimum standards of cultivation and of treatment of land, and of control of certain noxious weeds, adopted in 1917 and 1920 have been embodied in subsequent and permanent legislation.

Shortage of trained labour led to activity in the supply of substitutes, human and mechanical. Women did well, much better than was expected by many persons, and beliefs were entertained that the quota of female labour on British farms might be permanently increased, but very few remained more than a year or two after the War ended. To increase the labour force, steam-engines were used in field operations to their maximum capacities. Then tractors were introduced. Under the stimulus of high prices for grain, shortage of labour, and improvements in themselves, internal-combustion tractors were rapidly making their way in U.S.A. and Canada, and more or less rapidly in other grain-growing areas. Several thousands were sent to British farms, sometimes with poor results. There are difficulties in judging whether the administrative action taken to supply tractors eventually accelerated or retarded their introduction as part of the normal equipment of the larger and especially the more arable farms; on the whole it probably was retarding. Had a supply of reliable machines been available in 1919 and 1920, when farmers had spare purchasing power, when young men conversant with agricultural operations were available to work them, without the prejudice of previous experience of common mechanical failure and of very unsuitable machines, it seems probable that adoption would have been more rapid and widespread between 1919 and 1924 than it was. However this may be, the tractor was one of the new forces in agriculture and its influences have not yet fully worked themselves out. It not only reduced requirements of manual labour, increased the areas which could be cultivated and harvested in the time available for these operations, and reduced costs to some extent, it actually increased the area of crops available for sale by

removing horses and requirements of horse-feed. The Franco-Prussian war gave a great stimulus to live-stock breeding and production. The War of 1914–18, like the American Civil War, gave a great stimulus to the search for labour-saving devices in agriculture and particularly for grain-production. Doubtless, a part of the revolution which has occurred in grain-production would have come in any case, but the War brought it about in what has proved to be catastrophic form.

Farmers' gross incomes and their net cash balances rose with prices during the War, and the capital values of farming stock appeared to their owners to have risen in about the same proportions. Some few rents were doubled by 1919, but others showed no change, and the average increase was probably about 15 per cent. and certainly less than one-fifth, but many owners of land found it easier to increase their incomes somewhat in relation to expenses of living by selling their estates at the enhanced values than by the unpopular method of raising rents. While it is true that a considerable number of farmers undoubtedly wanted to buy farms in 1919 and early in 1920, larger numbers were forced to buy. Some people welcomed this change towards occupying ownership as putting Britain in line with what they assumed to be the best practice in other systems of agriculture. They would have fostered the change by deliberate policy. With the rapid change in the price-situation, however, there were soon demands for assistance to the farmers who had already purchased. The position is not very clear, but the changes of the War and immediate post-War period probably raised the proportion of occupying owners from about 11 to about 35 per cent. of the total. It was necessary to make some special provisions for supply of credit for purchase of farms in 1923 and 1928, but since 1925 there has been very little general movement towards transfer from landlords to tenants, and since 1931 it is quite possible that the number of occupiers who are owners and nominal owners of their farms has diminished. In view of the general statements about the conditions of the industry

since 1921, it is strange how few foreclosures on mortgages have occurred.

After the War the idea of developing co-operative purchase and marketing, but particularly the former, for efficiency and economy in the industry again gained prominence. What then appeared to be large sums were provided for work in education, propaganda, and organization, and some of the supermen of other war-time organizations were brought in to set right the commercial side of the industry. An Agricultural Wholesale Society was formed, but was caught in the commercial and financial maelstrom and disappeared before it had a chance to reach full activity. This failure, and the difficulties encountered by several other large distributive societies formed in the intensive campaign, gave co-operation a bad name, and were the cause of considerable losses to old-established societies and to individual farmers. A considerable number of marketing, especially dairy, societies formed during the War also got into difficulties, and generally the position and prospects of co-operation were weakened. But the idea of servicing the industry by co-operatives did not die out, although many farmers lost faith in it. National organizations remained in Scotland, Wales, Ulster, and in Eire, while the National Farmers' Union took over some of the functions of the English Agricultural Organization Society.

Optimism ruled the agricultural world at the end of the War. There was more money in it than any of the members of the industry had ever known before. Prices would be maintained partly or wholly by market conditions but partly, if necessary, by State support. Production would be increased: smallholdings would be created in large numbers and handsomely equipped to give new occupiers opportunities for themselves and a chance to serve their country in its most important industry. Farmers would buy farms to secure opportunities for themselves and their sons. Farm workers would be guaranteed minimum wages under State regulation, working conditions would be improved, and a considerable amount of new housing

would be provided. The State set out to train men for smallholdings, it established training and settlement colonies, groups and a considerable number of scattered holdings. A very few rural districts set out to provide new houses. The Agriculture Act of 1920 made permanent, as it was thought, the provision of guaranteed prices for wheat and oats, the system of regulating rates of wages and conditions of labour, the power to require minimum standards of cultivation and treatment of land, and it clarified and confirmed the provisions of tenant right in respect of compensation for disturbance. Here was the most radical and comprehensive Act relating to any industry ever placed upon the British statute-book.

Then this nation began to look at its War debts and its system and scales of taxation, and some other countries, notably the United States, followed suit. Many people had been amazed by what the War organization had proved the general agricultural and industrial systems could do in producing goods for use; if they could do so much when a large part of their labour-power was engaged in war, and another large part engaged in producing goods for immediate destruction, then they could feed and clothe and house the world in peace at standards it had never enjoyed before. There were those who thought otherwise: that before the commercial world began to enjoy any special benefits it should pay its debts. Throughout 1919 there was a frantic search for everything of the best, and especially of foodstuffs, which could be bought and consumed, and the search continued into the next year. Meanwhile the financial and commercial interests, especially the former, had been reconnoitring their position and laying their plans. Financial purists were largely in control of State policy of currency, credit, and finance, and those who had promised and apparently given so much to agriculture could not withstand them. Britain would make another bid for the financial and commercial leadership of the world. Currency was withdrawn, credit was curtailed, and within a few months of the passing of the Agriculture Act the collapse of the general level

of prices was seen to be inevitable. Stocks of grain grown on the War acreages were thrown on the market willy-nilly, but fortunately for British farmers stocks of animal products were low and prices were better maintained. Farmers were paid once under the guarantees of prices for cereals, but the guarantees were then withdrawn, the minimum wages system was also withdrawn, and other provisions of the Agriculture Act 1920 disappeared for the time being. Faith in agricultural education and research was probably at its highest during this period of crisis.

During the War there had been rapid growth of trade-union organization amongst farmers and workers alike. From 1913 to 1919 the workers' unions increased their membership from about 12,000 to about 190,000. The National Farmers' Union, founded in 1908, increased its membership from 27,000 in 1917 to 72,000 in 1919. But these unions were unable to prevent the withdrawal of the measures, recently confirmed, for the protection of their interests. The Farmers' Union secured payments to farmers in respect of current crops and negotiated large grants for agricultural education and research. It continued to increase its membership. The membership of the workers' unions fell away very rapidly, and they did not show much revival until about 1931. Nevertheless, their leaders and their central organizations continued to play much more important parts in relation to agricultural policy than they had played before 1917. Landowners had also organized in the Central Landowners' Association, but for a time there was conflict between the farmers' and the landowners' organizations and their influence on policy was weakened. The weight of the depression was to bring them, and at times all the class organizations, nearer together.

The features of this period were restriction of purchasing power in the hands of consumers, rising unemployment, return of agricultural systems to normal and even increased production, and within a short time the development of quality competition by imports such as had never

been known before. The basis of competition was changing from that of the pre-War period, with large quantities, low qualities, low prices, and unregulated competition, to high qualities, controlled export and controlled marketing, with less difference between the prices of home and imported products than formerly. At a time when the world's powers of producing foodstuffs were increasing more rapidly than ever before, when purchasing power was diminished by deflation, by economic dislocation and uncertainty, and by heavy taxation, many of the world's agriculturists turned to the production, preparation, and selection of quality goods as one of the possible remedies for their parlous conditions, and also as one of the means of securing use of their productive powers.

Taking the industry throughout, in its arable and grassland aspects and in its crop and live-stock production, its technical and economic efficiency was rising at rates previously unknown, and far more rapidly than the increase in numbers of consumers and more rapidly than their effective purchasing and consuming powers. The policies of developing agricultural research and education in this and other countries had borne and were still bearing their fruits. With industrial and urban unemployment, the traditional method of adjusting agricultural supplies to market demands by the migration or industrial transfer of personnel, from families of farmers and workers alike, was fairly rigidly restricted and in some areas nearly ceased to operate. In any case, it could not operate rapidly enough to ensure the necessary adjustment of supply to demand even if there had not been abnormal harvest conditions.

Farm wages in England and Wales were heavily cut. Farmers complained that the margins between farm prices and retail prices were too wide, and that if profits were not disproportionate costs were too high. Relatively high retail prices restricted demand and kept supplies hanging over markets: excessive margins reduced farmers' prices. In so far as margins on imports were wide, because rail, shipping, port, and general handling charges were high, they afforded a measure of protection to British agricul-

turists, but conditions nearer home were more intimately known and impressive.

At the request of farmers an inquiry into methods, costs, and profits of distribution of farm products was set up at the end of 1922 and within a few days a Tribunal was appointed to consider agricultural policy. From these may be traced a great deal of the subsequent development of policies and methods of implementing policies of assisting agriculture.

Every idea of social necessity, every possible principle of state action, every method or expedient, seems to have been canvassed during the last eighteen years. The most important factor in the situation was the tendency towards contraction of world trade, and the idea or the fear that Great Britain could not recover her supremacy or even her previous volume of trade. Alongside this was the growing tendency towards self-sufficiency amongst other nations, and the idea that the productive capacity of modern agriculture and industry had made unnecessary many of the international arrangements for the distribution of production on the basis of comparative costs in the exchanging countries. But the consequences to Britain's foreign trade were not to be accepted without a great struggle.

Conditions of credit, of currency, and of foreign exchanges were to be manipulated to restore confidence in the financial institutions of this country and to facilitate trade, and the general result of these manipulations was a steady reduction of price-levels. Somewhat naturally the idea of stable prices for agricultural products began to be canvassed. Relations between monetary institutions and conditions and agricultural prosperity had been discussed by Arthur Young over a century earlier, and again during the great depression of the nineteenth century. The ideas which now arose followed two main lines. The manipulation of currency and credit to maintain stable prices for producers generally, to secure equity in value transfers between debtors and creditors, and in its effect on contractual relations such as rents and wages, would be of

particular benefit to agriculture because of its extended production-periods, with the long time-lags between expenditure and price-realization, and its long-term contracts. Then, because of the influence of short-period harvests and long-period consumption, and because of variations in yield on given acreages, other regulations to affect prices would be necessary. There should be smoothing out of supplies, feeding markets according to use or consumption requirements, and gluts might involve selection of produce for presentation to markets with restriction of total supply offered, or other special measures to secure that they should not affect normal market demands. Any such type of activity required organization, and of that there was nothing likely to be effective in Great Britain; but in other countries various types of organizations were being evolved to deal with these problems.

Three measures were taken on behalf of the industry in 1923. The Agricultural Holdings Act of that year made permanent the extensions of tenant-right and, in particular, the provisions for compensation for disturbance. An Agricultural Credit Act proved entirely abortive as regards its provisions for short-term credit, but provided some relief for the people who required money for mortgages on farms which had been purchased. A year later, an attempt was made to stimulate the development of marketing organizations which were required, by a supply of credit. A number of loans were made to co-operative societies engaged in marketing agricultural produce, but these used only a small portion of the capital which Parliament had made available. Farmers appreciated more keenly the relief of one-quarter of the local rates on agricultural land.

Prices steadied and rose a little, and in 1924 and 1925 conditions in the industry improved. This, together with a change of Government and the troubling of the public conscience, made possible the reintroduction of the system of fixing minimum wages, but on this occasion without any statutory minimum and with executive power in the hands of local Committees without effective review and

revision by a central authority. Scotland remained without a minimum wage system until 1938.

The rise in prices was short-lived. Agricultural supplies were tending to be heavy. The cereal position was working up towards the accumulation of heavy stocks. Production of meat and dairy produce was meeting and exceeding effective market demands. Then, in 1925, it was deemed safe and desirable to return to the gold standard at pre-War parity, the financial power and honour of Great Britain was supposed to be finally re-established, and many agriculturists said that agriculture had again been sacrificed to finance and commerce. Prices drifted downwards again. The firms concerned with the Argentine meat trade fought their 'meat war' in 1927, and the British beef industry met its first great shock, expected thirty years previously, from which it has not yet fully recovered. The improvement of pedigree stock in this country, and the profitable export trade, were beginning to show their full economic effect. When the 'meat war' was settled, improvement in quality of supplies maintained intensive competition. The organization of Australian and New Zealand producers under State auspices and with State assistance has improved qualities of exported mutton and lamb, improved their market intelligence, and concentrated market control of their supplies.

The national policy was still one of free trade in foodstuffs and the stimulation of efficiency in production, but there was now added the encouragement and stimulation of efficiency in marketing. The investigations of price margins and of possible general economic policies in 1923, with the investigation of possibilities of stabilizing prices of produce in 1924, had led to the establishment of a Markets Branch in the Ministry of Agriculture and to the general extension and development of its activities in respect of economic conditions and movements in the industry. The first work of the Markets Branch was investigational. It began a series of surveys of the marketing aspects of both crops and live stock; it made comparative studies of marketing organizations in England and

U.S.A.; and surveys of some conditions in import trade. These studies, with the general examination and discussion of marketing problems and the examples and market influences of organizations in other countries, made a great change in public and agricultural attitudes towards marketing problems.

Conditions were changing in other lines. A substantial measure of protection was given to the pork industry by means of a 'sanitary' measure in the form of the Meat Imports (Pork) Prohibition Order 1926. On the other hand, the sanitary embargo on importation of Canadian cattle had been withdrawn in 1922, but some British fatteners had desired this change. The Pork Order was warmly if quietly welcomed because of its protective effect. In the same year, 1926, the Merchandise Marks Act came into force, and although this was not expected to be highly protective it was expected to remove elements of unfair competition and to assist in establishing preferences for home produce. Application of the Act appeared to be slow and reluctant, and farmers were disappointed with its results. But there were dynamic forces at work in the field of competition between British and imported produce. Improvement of quality of produce and of marketing technique and organization were more than sufficient to overcome any change made by the Merchandise Marks Act, and in some cases effective advertising was soon to be used in favour of the imported produce.

There was no promise that these new measures would provide relief for grain-producers, and the position of the more purely arable farmers was becoming desperate. The general election of 1924 had shown that in spite of many changed conditions the electorate was not prepared to accept any marked measure of protection, but a Labour Government could not ignore the position of arable farmers, and in 1924 they began to prepare the scheme for financial assistance to the sugar-beet industry. The Act was passed in 1925 by the Conservative Government. From 1912 to 1915 and again from 1919 to 1922 the Government had remitted the excise duty on home-

produced sugar, following the policy of establishing special industries contemplated in 1910. The Act provided a subsidy, but reimposed the excise duty at the preferential rate applicable to Dominions sugar. This was the first great step in what may now be regarded as the 'new policy' for agriculture. The rapidly developing industry provided a great measure of relief for a large number of arable farmers, but mainly in eastern England.

While ideas and movements in marketing were developing there were other things to be done. In 1926, it was necessary to liquidate the results of the post-War policy of land settlement, which was now seen as a social rather than an agricultural movement. Indeed, this liquidation marks the great decline of the ideas that smallholdings would greatly ameliorate the conditions of farm workers, and that they provided a highly desirable modification of the general economic structure of the industry. Smallholdings will always have their advocates, but until the experience of 1919–26 is forgotten the State is not likely to indulge in any campaign for a rapid increase in their numbers. Attention turned markedly to housing, and the Rural Workers' Housing Act of 1926 provided for reconditioning of existing cottages by the aid of public loans and subsidies. Then, in 1928, two major actions in relief of the industry were undertaken. The Agricultural Credits Act provided for loans for the purchase of farms, a provision now used to the amount of about £13 million, but its provisions for short-term credit on the security of bills of sale disguised as 'agricultural charges' proved abortive. By an interesting coincidence, agricultural credit and relief of rates were dealt with in the same year, as they had been in 1923, and in 1928 agricultural land and buildings were relieved of the remainder of the rates which they carried. Thus was completed the process which had been begun in 1890 and continued in 1923. As parts of State policy, provisions for credit other than farm mortgages and small-scale co-operation had proved disappointing in their service to the industry. In the meantime the farmers had been making their own great

contributions to marketing experience. The beet-sugar enterprise helped in the development of experience and tendencies in marketing, for, from the beginning, prices of beet were determined by collective bargaining between the National Farmers' Union and the grouped factories, and producers' representatives were placed at factories to watch their interests in weighing and analysis of deliveries.

Other things had been happening which were to accelerate progress. At the Imperial Conference of 1923 the Dominions had been promised a system of Imperial Preference in British customs duties, but the general election of 1924 made it impossible to implement this promise. Following on the general election of 1925, which returned a Conservative Government, an alternative was found in the stimulation of the activities of the Imperial Economic Committee and in the establishment of the Empire Marketing Board, with large funds at its disposal, in 1926. Part of these funds was devoted to development of marketing in Great Britain.

Since 1923, a system of collective bargaining in the sale of milk, more or less copied from organizations operating in the United States of America, had been successfully operated in England and Wales by the National Farmers' Union and organizations of milk-buyers. In Scotland, where experience of farmers' co-operation in the milk trade had been more satisfactory than that in England, the Scottish Milk Agency had been formed in October 1927 and had dealt with milk on a fairly large scale. A hop-growers' co-operative society, English Hop Growers, Ltd., had included over 90 per cent. of the growers in its membership, and for a time had promised success, but the recalcitrant minority brought a useful society to naught. Ideas of the equity and of the methods of pooling supplies and returns were received from U.S.A. and Canada, and principles of compulsory marketing adopted in other Dominions began to exercise some influence on British ideas of marketing systems.

With the information services of the Empire Marketing Board, the Ministry of Agriculture, and some other

organizations, and propagation of ideas from several sources, policy was soon to show very rapid development. The distinguishing features of the Board were the very handsome financial provisions made for it, and the close association of civil service, agricultural, and commercial elements in its administration. While it lived it made splashes in more senses than one, and it certainly introduced new ideas and methods of publicity into the propaganda systems of the State.

The first important fruit of the new systems for studying marketing and stimulating reforms was the Agricultural Produce (Grading and Marking) Act, 1928. The first grading scheme was that adopted for apples and pears in the autumn of 1928. There are now seventy-eight schemes in operation. But there is also a special grading scheme for fat stock under the 'grade and dead-weight' system of selling, organized by the Ministry of Agriculture in several wholesale meat markets. There is also a special grading system for fat cattle under the Livestock Industry Act since 1937, and under the earlier provisions since 1934. Under the auspices of the Ministry of Health and with the assistance of the Ministry of Agriculture and Local Authorities there had been a system of grading milk, the 'designated' milks, since 1920, but while this had considerable educative value its commercial importance had not been very high. With the adoption of all graded milk by the Milk Marketing Boards, and the creation of the special 'accredited' grade in England and Wales, a very considerable portion of British farm produce is now sold under grade regulations, and considerable amounts are sold under the National Mark. Perhaps the National Mark has been on the whole more useful to the secondary products, like preserves, cider, &c., than to the primary products. The system of grading and packing eggs under the National Mark, however, carried supplies into markets which they had never previously entered with success, and by expanding the market expanded the opportunities for production. There are other examples of the same kind, and on the whole the systems of grading

and marking, with new systems of packing and presentation, increased the competitive powers of the home products.

This, however, was not enough; organization was required; and the Agricultural Marketing Act of 1931 made radical provisions for it. During and immediately after the War there had been much talk about 'self-government in industry': here were powers of self-government for each group of producers of each agricultural product if they wished to use them.

The first Act (1931) provided that when not less than 50 per cent. of the registered producers in a defined area voted on the proposal to establish a Scheme, and two-thirds of those voting were in favour of the proposal ($33\frac{1}{3}$ per cent. of registered producers and product), a compulsory Scheme might be established. Such schemes could provide powers for regulating the marketing of produce or for its actual purchase and sale. In addition, the Schemes could provide for sale of farmers' requirements, for credit to registered producers, and for the pursuit of various other objects. The Act of 1933 amended that of 1931 in various particulars, but extended the scope by providing for the regulation of imports of competing produce when Marketing Schemes had been established or were in process of formation, and for the establishment of a Market Supply Committee to review imports and conditions of general supply, and to advise with reference to regulation of imports. The provisions for Marketing Schemes were accompanied by elaborate provisions for appointment of a Consumers' Committee and a Committee of Investigation to safeguard the consumers' and the general public interests. For a Marketing Scheme covering one or more secondary products derived from a primary product, with a Scheme for the primary product, there were provisions for joint organization under Development Schemes covering both sets of interests. The whole set of provisions for Marketing Schemes and related organizations, as extended by the Bacon Industry Act of 1938, are now extremely elaborate and complicated, and their

economic effects are mixed up with those of the regulation of imports and the supply and administration of subsidies.

Producers were inclined to say that the powers available under the first Agricultural Marketing Act were of little use, unless accompanied by powers of controlling imports. The general policy of the party supporting the Government which promoted the Act included provisions for Import Boards. But subsequent experience has proved that British producers made their greatest economic mistake when they failed to appreciate what was offered to them in 1931, and to adapt the provisions of the Act to other products, particularly to live stock and eggs and poultry. The Hops Marketing Scheme, adopted in 1932, has been highly successful—perhaps too successful within narrow limits—but the market in which it operates is peculiar and peculiarly privileged. The Milk Marketing Schemes, of which there are three in Scotland in addition to the large Scheme covering England and Wales, have been highly successful in making the very best of all the markets for milk, in running efficiently at low cost, in returning to their producers practically everything that their markets could afford them, without contraction and possibly with a little expansion of their markets in a most difficult period. The Potato Marketing Scheme, which does not sell potatoes, but controls areas planted and endeavours to regulate the flow of supplies to market and to advise growers on market values, has also afforded a great measure of economic protection to all producers who registered in 1934. The probabilities are that there are sufficient dynamic factors in the enterprise of growing potatoes to prevent the present Scheme and its Board doing any serious injury to consumers' interests. The Pigs Marketing Scheme had a chequered career, and very little now remains of producers' control. But in spite of fears, failures, and complaints the Scheme offered opportunities of developing production which were taken by a minority of relatively large-scale producers, and the net result has been an increase in production with some, if not too serious, damage to consumers' interests. The management of the

Bacon Marketing Scheme has stood out in strong contrast to that of the Pigs Marketing Scheme, and curers were willing to take every opportunity of extending their industry, and to judge opportunities on business bases. For milk, hops, and potatoes, the Marketing Schemes have provided systems of self-government which from the producers' point of view must be regarded as highly successful. The shortcomings of the Pigs Marketing Scheme, and of its administration, with fears of some of the results of the more successful Schemes, assisted in preparing the way for ideas of control or supervision by forms of Public Commissions, established by the State to supervise marketing in one branch or another of the industry. While the principles of operation and the administration of Agricultural Marketing Schemes are matters of first importance to their registered producers, and of considerable importance to the consumers of their products, students of policy may have to look elsewhere for dominant guiding ideas. There will probably never be any more Marketing Schemes under the Acts of 1931 and 1933, and those which are in existence under those Acts, for milk, hops, and potatoes, may be modified in the future. The failure to adopt a Live-stock Marketing Scheme led to the formation of a special Cattle Committee to administer the subsidy on fat cattle under the Live-stock (Emergency Provisions) Act, 1934, and when this subsidy was continued under the Live-stock Act of 1937 provision was made for appointment of a specially constituted Live-stock Commission, which is given very considerable powers of influencing and possibly of controlling the systems of marketing live stock. The powers of control are in the Act, but the difficulties of using them must be very great, and may prove insurmountable. Much depends on the attitudes of Parliament, and recent events in connexion with the ill-fated Milk Bill of 1938 lead to doubts whether this and any similar Parliament would favour use of the powers which were given to the Commission only a short time ago. But powers of obtaining and using market intelligence, of forming practical

ideals and standards related to live-stock markets and marketing, and powers of persuasion and offering advice will remain with the Live-stock Commission. A very careful review of experiences of and under the Milk Marketing Schemes led to the recommendation of the establishment of a Permanent Milk Commission to supervise the working of the schemes in the public interest and, to some extent, in the long-term interests of producers, but this proposal has recently been rejected. In view of the history of the Pigs Marketing Scheme, it seems fortunate that the Bacon Industry Act, 1938, provided for an overriding authority in the form of a Statutory Development Board, with a strong element representing general public interests. This Act marks a long step from the principle of producers' control set up by the Agricultural Marketing Act, 1931.

For the moment, any effort directed towards securing efficiency and economy in the distribution of foodstuffs, and especially in retail distribution, seems doomed to failure. There must be a review of the principles of the Marketing Schemes and of the other types of organization set up as palliatives or substitutes, for at the present time there is no clear policy. A new process of examination of experience and of education is necessary in the interests of both producers and consumers. If this be not secured, it appears that a great deal of the progress made in marketing since 1924 may be thrown away, and it is a fact that agricultural producers did not take full advantage of the opportunities of self-government that were offered to them in 1931–3, either in number or quality of organizations. Demands for other forms of assistance, particularly financial, have arisen and will arise, to a considerable extent, through failure to secure effective market organization. Almost everywhere the farmer turns, as buyer, he meets organized, regulated selling. Trade in fertilizers, concentrated feeding-stuffs, and agricultural machinery is regulated and controlled at practically every point. And everywhere the farmer turns, as seller, he meets either organized, regulated buying, or

groups of buyers in the possession of better market intelligence or more effective methods of safeguarding their group interests than any which unorganized sellers, as in the live-stock industry, can apply. If farmers and their organizations are unable to find effective methods of reducing the physical and monetary costs of assembling, transporting, marketing, and distributing farm produce, then society must find them in its own interests, for otherwise much of the value of technical and economic efficiency in agricultural production will be lost to consumers.

The briefest review of the experience of Agricultural Marketing Schemes carries the spectator far beyond the point at which begins the main change in agricultural policy as many agriculturists see it. Political Labour, which had prepared the way for the beet-sugar subsidy, was particularly susceptible to pressure from the Eastern Counties, where the agricultural workers' unions are strongest. While the beet-sugar subsidy had helped, there was still distress in these counties when the second Labour Government was in power. Before it completed its short life, this Government had begun to prepare the Scheme which was embodied in the Wheat Act, 1932. Because imports of wheat exceed home production in the ratio of five to one or thereabouts, it is possible by raising a relatively small levy on imports of wheat and wheat flour to pay a fairly high subsidy on the home product. This was the principle followed, with the extension of the levy or 'quota payment' to home-grown wheat made into flour, and a specially constituted Commission was appointed to administer the Act. A minimum average or standard return of 45*s.* per quarter was guaranteed for millable wheat, but the individual farmer's return consists of the price realized by his own grain *plus* the difference between the ascertained average yearly price and the standard return. This Scheme has worked extraordinarily smoothly. Nothing which has been done by the State has given farmers so much unalloyed satisfaction, and because of the low price of imported wheat, and the relatively low prices of the flour which include the deficiency levies paid by

millers, the public have not made any serious complaint. Indeed, most of the consumers, most of the time, have been quite unconscious of any tax on their bread-supplies. The position of bread in the dietary of the British working classes, and in their scale of appreciations, has entirely changed during the period covered by this review. The success of this system of deficiency payments on wheat-supplies led partly to the development of ideas, even promises of levy-subsidy schemes—levies on imports and subsidies on home production—in other spheres. These promises, for various reasons, could not be implemented. But subsidies direct from the Treasury, raised by the ordinary methods of taxation, have been provided for manufacturing milk and fat cattle, 1934, for barley and oats, 1937, and under certain conditions for bacon pigs, 1938, as well as being continued for beet-sugar. Indeed, it has been said that the total of these subsidies, including that on wheat, has reached £16 million in one year. The actual sums which the State may have to provide under its obligations to pay subsidies on produce are not fixed, and it appears that the total may vary between twelve and twenty millions sterling from one year to another.

But marketing reform was not enough: subsidies on wheat and sugar-beet were not enough: and there came the great change to the regulation and the open taxation of imports. The financial and economic crisis of 1931 shook many allegiances, many previously fixed ideas, but it brought no greater change than the first serious and open break in the traditional policy of free imports of foodstuffs. The Horticultural Products (Emergency Customs Duties) Act, 1931, was advocated on two grounds: that by reducing imports it would assist the international financial exchange, and that as the products themselves were luxury goods reduction in their purchase would be good for the nation. It was said to be an example of sumptuary legislation of which the latest previous example was to be found in the sixteenth century. The rapidity and certainty with which the Bill was prepared and applied leads to the assumption that it had been partly prepared

before the crisis and these justifications were useful afterthoughts. However, there was a good economic reason for its introduction, for some of the horticultural industries concerned in this country had the character of 'infant industries', and a little protection would enable them to expand while reducing unit costs of production, and thus to feed the markets with supplies at the previous price-level: and so it proved.

Events then followed quickly. The Import Duties Act was passed early in 1932, and although many agriculturists were disappointed by the long free list for foodstuffs, it took a step in the direction in which they wanted to proceed. The Irish Free State (Special Duties) Act followed in July of that year, and although there were special reasons for these duties, they added to the general protective system which was coming into being, and particularly to the agricultural section of it. Then the Ottawa Conference followed, and the agreements reached with Empire countries and the Act which followed them both restricted the Government in taxing Dominions produce and set it free to exercise some controls of foreign supplies. It is impossible here to follow in detail the intricacies of the protective system. But the first and most important controls exercised were those of quantities. The expedient of the 'quota' or quantity regulation, at that time in well-established use in some European countries but new to this country, was expected by the expert advisers of the Government to be much more effective than tariff protection.

The nation and the State travelled far and fast in marketing and economic policy between 1924 and 1931. The first arrangements for restriction of supplies in the autumn of 1932 were said to be 'voluntary quotas', but probably there was truth in the statement of a foreign observer that never were volunteers more unwilling or under greater pressure. These first quotas had no statutory basis, indeed no specific basis in any written law; they rested on the general powers of the Executive to do what is necessary for the welfare or the safety of the State.

But they may yet provide interesting and, as some people may think, dangerous precedents. As it was possible to reduce the people's food-supplies by Executive action only, it may be possible to establish Import Boards by the same action with equal legality, but possibly not with equal comfort to some of the people who welcomed the 'voluntary quotas'. Under the Agricultural Marketing Act of 1933, the Board of Trade was given power to regulate the quantities of imports of any product for which a marketing scheme was in force or projected, but most of the quotas still continued to be of a voluntary character. They did succeed in making substantial reductions in previous supplies in some products, of preventing increases in supplies in a number of others, and generally they assisted in stabilizing market conditions in this country as much as they could be stabilized with the reductions and the uncertainties in consumers' purchasing powers at the period.

In 1933 began the process of making and revising trade treaties and agreements with many countries, in order to implement the new policy of taxing, or restricting or controlling, the imports of various foodstuffs. Many agriculturists have never been satisfied with the protection that has been given them by regulation of quantities or by customs duties, but there has been a considerable degree of it.

Quotas are now in force on a 'voluntary basis', by Order of the Board of Trade under the Agricultural Marketing Act, 1933, under the Ottawa Agreements and trade treaties, and shortly there will be quotas for mutton and lamb under the Livestock Act, 1937. Provisions for control of prices, of semi-official character, are associated with some of the arrangements for control of supplies. Duties are in force under the Import Duties Act, the Ottawa Agreement Act, the Beef and Veal (Customs Duties) Act, and recently heavy duties were levied under the Irish Free State (Special Duties) Act. In 1936–7, when all these Acts were operative, the yield of duties on foodstuffs more or less competitive with home produce

was over £16 million. The special duties on Irish produce have been lifted, but it appears that the yield of such duties now in force may rise to £20 million a year without counting the special levies on wheat and flour under the Wheat Act.

From the beginning of 1937, quantities of imports of beef and veal have been regulated by the International Beef Conference and the Empire Beef Council set up at the instigation of the Government of the United Kingdom, and having Chairmen appointed by it, with a Secretary paid by the Board of Trade, but having no specific statutory authority. The Livestock Industry Act, 1937, removed control of meat (other than bacon and hams) from the operation of the Agricultural Marketing Act, 1933, and gave the Board of Trade specific authority to control imports of live stock and meat as regards both quantities and qualities. But it was not intended that this power should be used except in the event of the failure of regulation by the Imperial and international cartels set up and supported by the British, Dominions, and Argentine governments. Finding expedients for implementing changing agricultural policies has involved quite an element of constitutional development which, doubtless, will be examined with great interest in the future, and not only for reasons of curiosity. The Sydney Conference of the Empire Producers' Organizations, 1938, has proposed the establishment of Commodity Councils (on the lines of the Empire Beef Council) for mutton and lamb, pig meat, and dairy produce. These resolutions appear to exclude the third clause of the popular version of the Ottawa principle—the local producer first, the Empire producer second, and the foreigner third.

The electorate of the United Kingdom will indeed be supine if it allows any private organizations to control and restrict its oversea supplies of foodstuffs, and, in so far as the control of Britain's purchases (and the exports of the Dominions and other countries) must have a big influence on other lines of commerce and on British industrial production and sales, it appears that specific non-agricultural

groups may have strong objection to such forms of direct control of international trade by private organizations.

Besides these traditional policies and major changes there have been many side-lines of general social policy in relation to agriculture or of direct agricultural policy. During the War, farmers paid income-tax on the basis of assessment at double the rent of their farms, but in 1922 the basis was changed to a single rent with the alternative of assessment on actual net profits with choice of turning backwards and forwards to one basis or the other. Since the removal of the rates on agricultural land and buildings, it seems probable that in relation to their effective net incomes farmers have borne lighter burdens of direct taxation than any other group in the community. Relief from income-tax has undoubtedly helped to maintain the general supply of farmers' capital and for many individuals has considerably assisted saving. In 1918 there was adjustment and at least some reduction of the burden of tithes, in 1926 there was further adjustment, and in 1936 there was a transfer of tithe to the State, with reduction of the burden on land, making the State responsible for the payments to the beneficiaries. Tithe is now the only burden to be removed from land, unless, indeed, the nation should become the owner of the land and then proceed to let it rent free. Ever since the pre-War Town Planning Act there has been a slow growth of opinion in favour of control of the use of land as between agricultural and many other uses, and there has been accumulation of a great deal of experience of surveying for planning, with some of planning itself. This movement is bound to develop in the future. Since 1926, in 1931, 1932, and again in 1938, attention has been paid to rural housing, and the latest Act should assist in producing a considerable increase and improvement in supply. During the years 1929 to 1931 there was provision for financial assistance in the provision of water-supplies for farms, and also for field-drainage, and provisions for assistance of village projects for water-supplies in 1935. Although there have been several interesting experiments and demonstrations

in the special supply of electricity for farms and rural areas, and considerable progress has been made in some Midland counties, there has not been any general solution of the problem of equitable and economical conditions of supply. This problem still awaits solution.

Drainage of land has received a good deal of attention, and the process of removing unwanted water is slowly moving back from the sea to the most distant of the farms. Financial assistance is now available for the brooks and main drains which serve several farms or properties. It remains to be seen whether the nation will again provide free funds for the internal drainage of farms and fields which are individual and private property. But in one of its latest developments of policy the State has provided subsidies for the supply of lime and basic slag.

Had the State nationalized the land at any time between 1921 and 1924, it would almost certainly have made a good bargain and could have safeguarded many interests in its use for agricultural and other purposes. It seems necessary to find some method of introducing the public capital of the State for the purpose of re-equipping and developing farms with adequate provisions for security. Part of the Agricultural Land (Utilization) Act, 1931, which has never been used, provides one method and set of powers for dealing with some aspects of the problem. Possibly in the near future it will only be necessary to find a decent or attractive disguise with which to cloak it in order to secure nationalization.

The State continued to extend and strengthen agricultural research and education. But almost everywhere new aims are set before research and investigation in relation to applied science. The world does not want spasmodic production, it needs designed if not controlled production, and regulated though not restricted supply: it desires plentifulness with regularity; variety with high quality. Hence the emphasis in the more practical research is on certainty of yield in production; securing quality in production, securing safe and, whenever possible, improving storage. Entomology and mycology have risen

in importance, and knowledge and practices in spraying and dusting, in times of sowing, and other operations for avoidance or control of disease have undergone enormous change. But even cultivations and manuring are now often arranged to control yields. There has been much research on methods of storage by low temperature and 'gas' methods, and for Great Britain and the Dominions this was specially stimulated by the Empire Marketing Board. Organized research came to the aid of marketing.

The newest policy is that of 'the marriage of agriculture and health'. But as agriculture seeks mainly the dowry which health and its social relations can so ill afford in any form of direct payment, it is difficult to judge what form action may take. A little practical progress has been made in the supply of milk for school children and some similar schemes. Great changes in dietaries and in nutrition have been discussed. These require even more far-reaching changes in the general production and distribution of wealth in society at large, of which there are no present signs. Education and propaganda may do a little in diverting consumers' purchasing-power from one foodstuff to another, but their permanent power in this direction is easily overestimated. They will do very little in diverting purchasing-power from other goods, services, and satisfactions to foodstuffs and nutrition. Control of use of productive powers and general control of supplies, as in totalitarian states, may shape dietaries, but even this has never yet brought the standard of nutrition desired by the idealists. The achievement of this standard by methods which would increase total demands for foodstuffs requires that all the forces of production be set free for the supply of all the consumers' needs and demands, in the proportions fixed by consumers according to their appreciations. A little can be done by control, a little by education and advertisement, but the effect of these on dietaries and nutrition is strictly limited by the low standard of purchasing-power and the many wants of those who need better dietaries. Some of the methods may tend to reduce total demands for foodstuffs. It is strange how

many people who refuse to believe that it is possible to make men sober by Act of Parliament, and who know it was impossible in the United States, still believe that it is possible to make them all strong by the same instrument.

If the question be asked—What have these changes in policy achieved?—many answers may be given, and answers are bound to be complex. They have not maintained all the pre-War or even post-War area in cultivation: that was impossible in view of requirements for other uses. They have not kept the pre-War or the post-War area of arable in arable use: that again was almost certainly impossible in view of the technical, mechanical, economic, and commercial changes in areas producing oversea supplies of grains and oil-seeds. They have, however, with these and other technical and economic changes, led to an increase in annual gross output. They may have led to a slight increase in total net output, but in any case they have led to considerable increases in both gross and net output per person engaged in the industry. They have not stopped, nor were they ever likely to stop, 'the drift from the land'.

Yet they have enabled and required farmers to pay such cash wages as have maintained the real wages of agricultural workers. The general condition of these workers has improved, but partly as a result of general social legislation as for health and pensions and unemployment insurance (not provided until 1936) and to a small extent for housing and education, and partly also because of reduction in the average number of children per family. Conditions here are complex, but technical and other changes leading to higher outputs per person, with the measures taken to safeguard prices or returns, and the actual migration or industrial transfer of part of the workers, have enabled those remaining to improve their standards of living. Then what of farmers? Bankruptcies and similar failures have at times been high and at other times amazingly low. The productive capacity of farmers' capital has not diminished but has rather increased, but of course if capital values were compared in the present £s

with those of 1919, a decrease would almost certainly be shown. On the other hand, if comparison were made in terms of present £s and 1913 £s, an increase in capital would be found. Many farmers have made money, and saved capital, in the period since 1920. On the average, it would be judged, they have improved their standards of living in this period; the occupiers of small and medium-sized farms have certainly improved theirs since 1913. At the same time, it would still be true that the average rates of remuneration of labour, manual and managerial, and of capital, are lower in agriculture than in any other industry employing mainly men. Except for some short periods and for relatively small areas, there has been demand for farms, but this may be due partly to the diminishing area of land available and partly to difficulties of finding alternative occupations for the capital and working capacities of farmers and their sons. In any case, in spite of all complaints, there has not been any shortage of supply of farmers. Competition for farms assisted in maintaining rents, but landlords generally obtained some advantage from the relief of agricultural land and buildings from the burden of rates. For short periods, and on particular types of land, especially perhaps light arable, there have been difficulties in letting farms. Probably cash outgoings of landlords have increased and net incomes on the average have shown a little decrease, but those owners who have been able to sell considerable areas of land for non-agricultural uses have been handsomely recouped for any other losses. There has been an enormous transfer of power in the direction and control of use of land and in the general direction of the agricultural industry from landowners to farmers, and with this a very considerable transfer of power in local government and administration. These changes have been due to the Agricultural Holdings Acts, to the growth and development of the National Farmers' Union and to some Marketing Schemes, to a new sense of status in the rank and file of farmers, probably as a result of the better general education under the improved system which

arose under the Education Act of 1902 and subsequent provisions.

There is often temptation to speculate what would have happened if, from 1926, the nation had not began to subsidize arable farming, and if, from 1931, it had not extended the system of subsidies and provided considerable measures of protection, and the speculation is not entirely an idle one. No one who knows the economic and political history of Great Britain can imagine that all the expedients that have been and are being used will remain as parts of our agricultural and general economic systems. On the other hand, he would be a bold prophet who foretold which of them or how long each of them will be retained. In the absence of subsidies and the various forms of protection, with supply of scientific and technical advice and market intelligence, with market organization as under the Agricultural Marketing Act of 1931, the industry might have been smaller in acres, much smaller in numbers of men both family and employed workers, probably a little smaller in output, yielding average incomes higher than those in fact earned under the existing system. And it would by now have solved its fundamental problems of what sizes and types of arable farms can be permanently maintained, and of what size and types of beef industry can be maintained into the farther future. These two problems remain for solution, for it is extremely unlikely that the nation will continue to carry these industries in swaddling clothes, and it is practically certain that there will never be any such technical and economic changes in the production of competing supplies as will enable them to stand on their own feet in their present forms. The only long-run justification for the fat-cattle subsidy would be that it assisted some producers to make such adjustments in their systems of production as would enable them to continue without the subsidy, and others to change to alternative lines of production with the least necessary loss of capital resources, but there is little sign of these changes. Under the worst of possible circumstances the long-run justification of the wheat deficiency

payments may be found in the War-time production of the retained arable. In the absence of this, the only other justification would be that they enabled owners and occupiers of farms to shape and equip them, to develop such combinations of crops, or possibly crops and live stock, as would enable them to continue profitably in the absence of the payments. There are some such trials and changes going on, but there are far too few of them. Doubtless this sounds harsh, and it may even appear stupid at a time when farmers are asking for a general system of 'price-insurance' somewhat similar to that of the Wheat Act. But it will be a sorry day for British agriculture when, in a State retaining its essentially capitalist character, it depends much more upon subsidies (or whatever they may be called) than it does to-day. Society and the State are not in the habit of paying paupers at rates which do not leave them substantially in the position of paupers in relation to the rest of the community.

Neither the State nor agriculturists have ever defined the chief aims of agricultural policy, and for the greater part of the time both parties are pursuing conflicting and to some extent mutually destructive aims. In view of the position of their earnings, which has been described, agriculturists should seek for their own benefit, and for that of society, such methods of production and market organization as will raise the value of net output per person and thus raise average earnings. But they will mix up this aim with those of using the last possible acre, the last possible man in production, and getting the last ounce in production, and these aims cannot be pursued at the same time. Fortunately for them, farmers' theories and practices are often at variance. If the State requires that the last acre and the last man shall be used for the last ounce of production, then it must be prepared to find and use or make a helot class of agriculturists or to provide for such change in agricultural price-levels or such distribution of subsidies as will clearly begin to impoverish the nation. Unnecessarily intensive agriculture is an expensive luxury:

it is more like a city man's garden than a farmer's farm. Fortunately, the State has been wise enough to repudiate the aim of using the last acre and the last man for the last ounce of production. It has not yet formulated the aim of securing the optimum production at unit costs not higher than the costs of delivered imports under conditions in which agricultural labour and capital are remunerated at about the average rates prevailing in other productive industries. The State may formulate a standard between this and 'the last ounce', but its success in doing this will depend on how much it is prepared to spend, and on the extent to which it is able to exploit agricultural labour and capital. It might select certain branches of the industry for maintenance, or certain processes for assistance, for reasons of national defence. Whatever happens, it cannot afford to forgo any of the methods of raising technical and economic efficiency in the industry. Defence as well as opulence demands efficiency and economy in production, transport, and marketing.

AGRICULTURAL EDUCATION IN COLLEGE AND COUNTY

By J. A. HANLEY

THE development of state-aided agricultural education, as we know it to-day, really began only fifty years ago, but it has incorporated so much of the past that it is worth while looking back over an earlier period of something like a century. This was not a period of great activity, but it was remarkable for the efforts made privately and by all kinds of societies to provide, for those engaged in farming, some instruction in the principles underlying agricultural practice. Before ever State aid was considered for agricultural education various interests were trying to find methods of improving agricultural practice by means of classes, demonstrations, and competitions. These pioneer methods, especially demonstrations and competitions, have ever been popular means of arousing interest amongst rural workers. Up to the present time they have existed in the form of clean milk competitions, ploughing competitions, pasture competitions, and all kinds of workers' competitions, and have offered a starting-point for agricultural instruction.

Up to the end of the eighteenth century there is very little progress to record. The Royal Society of Arts was founded in 1753 by a few men interested in promoting arts, science, manufactures, &c., and had a membership of 2,500 by 1762. There were then no departments of State dealing with agriculture or forestry. Almost the only method of 'encouraging' arts, science, &c., for a century was the award of premiums for suitable objects. The Society's biggest efforts, at first, were for agriculture; they had the assistance of Arthur Young, who became Chairman of the Committee of Agriculture in 1774. The prizes offered covered a very wide range—improvement of crops, introduction of new crops and varieties, and new farm machinery; the provision of winter food for live stock

received special attention, and afforestation, too, received a fair share of these awards.

The Bath and West of England Agricultural Society was founded in 1777, the Highland and Agricultural Society of Scotland in 1784. This latter society obtained special powers in connexion with agricultural education in 1856, and it began to conduct an annual examination in 1858.

Lectures in agricultural chemistry were given in the Royal Institution from 1802 to 1812, and in 1806 the Bath and West Agricultural Laboratory was set up. The Royal Agricultural Society of England was formed in 1838, and it soon began to foster interest in agricultural education and research. It set up a special education committee in 1863 and its examinations in the science and practice of agriculture were started five years later. This examination was amalgamated with that held by the Highland and Agricultural Society of Scotland in 1900, and up to the present time the joint diploma is regarded as a valuable professional qualification. The Farmers' Club and the Central Chamber of Agriculture arranged for several papers to be read on agricultural education between 1859 and 1873.

At that time it was difficult to find teachers of 'Agriculture', but in 1875 the Highland and Agricultural Society of Scotland was instrumental in getting the Science and Art Department at South Kensington to add 'Principles of Agriculture' to the list of subjects for instruction for which grants in aid could be earned. A lecturership in Agriculture was established at the Normal School of Science, South Kensington, in 1882. The course of study differed from those at the colleges at Cirencester and Downton in that it extended to four years and was almost entirely given up to pure science. The 'Principles of Agriculture' were dealt with in the fourth year. Long and short courses for teachers were given at South Kensington. They were started in 1875 and continued until 1897.

The Department also held examinations and awarded certificates for those attending evening classes throughout

the country. These classes were mainly in pure science and were taken by local teachers. It arranged refresher courses for teachers at South Kensington during the summer vacations.

In the early days of county agricultural education several counties took advantage, for the time being, of these arrangements made by the Science and Art Department. For example, in Kent it was decided that instruction for agricultural workers could best be provided by the masters and mistresses of elementary schools. In 1891 a scheme was devised whereby public elementary school teachers could attend classes in preparation for the Science and Art examination. At six centres in Kent the number of school teachers registered was 217.

Of particular interest, too, is the part played by some of the smaller local agricultural societies; the help and support of prominent local agriculturists thus enlisted was the means of establishing, later, a number of local teaching centres. Some of these, again, have been developed into some of our modern schools and colleges.

One example may suffice to show how powerful some of these earlier local interests became: The South Cheshire Agricultural Society was established, in 1838, for 'the encouragement of agricultural enterprise and the promotion of industry and moral habits among the labouring portion of the community'. It was concerned mainly with shows, prizes for ploughing, and so on, until 1885, when a Committee was charged with making arrangements for holding discussions on the occasion of the annual exhibition. In 1855 four papers were prepared and duly read and discussed on the day preceding the annual show, before an audience of about 400 gentlemen interested in agriculture. The Committee recorded gratification that this society should have been the first to have added so practical and interesting a feature to its annual exhibition. It was the Cheshire Chamber of Agriculture which first set on foot systematic schemes of agricultural education locally. The Chamber was established in 1868, and it included most of the big landlords. From the outset this

body was concerned with scientific progress. There were papers on subjects such as cattle plague, pleuro-pneumonia, adulteration of feeding-stuffs, and artificial manures in 1868, 1869, and 1870.

As a result of a paper read in 1874 on the education of the agriculturist, a Committee was appointed to consider facilities for educating farmers' sons and to report as to the possibility of utilizing existing grammar schools for this purpose. In 1876 boys were already attending Sandbach Grammar School at the expense of the landlords, and were being taught subjects such as chemistry, botany, animal physiology, and land surveying by a special teacher. In 1879 two Cheshire boys were awarded scholarships by the Royal Agricultural Society of England. In 1885 the Society memorialized the Privy Council, asking for more prominence in the teaching of agriculture in the principal standards of national and board schools and the allocation of grants for evening classes in agriculture. A private company was established in 1886 to set up a model dairy to be used as a place of tuition in cheese- and butter-making, the shares being taken up by the landlords and other members of the Chamber. A farm was rented at Worleston, and a cheese-making farmer, Willis by name, was appointed to take the classes. This place ultimately developed as the Worleston Dairy Institute. From 1890 the County Council took over agricultural education and established, first, the agricultural college at Holmes Chapel, and later, the farm institute at Reaseheath.

There was very little agricultural education at the universities until the end of the nineteenth century. In 1790 the first chair of Agriculture was established at Edinburgh, and in 1796 the Sibthorpian Professorship of Rural Economy was established at Oxford. This latter provided little more than a few lectures each session, lectures which, whilst appearing at first to have little influence on subsequent developments in agricultural education, did, however, provide for courses of lectures by eminent men, such as John Henry Gilbert and Robert Warrington. It was not until 1907, when the Sibthorpian Professorship was

renewed by St. John's College, that agriculture and rural economy became recognized as subjects of study leading to a degree. In 1868 the Highland and Agricultural Society of Scotland obtained an increase of £300 per annum to the Edinburgh Professor's stipend, half of which was found by the Society and half by the Government.

The influence of this early chair of agriculture at Edinburgh on subsequent teaching of agriculture can scarcely be exaggerated. Somerville (graduated 1887), Middleton (1888), Gilchrist (1889), Seton (1894), all pioneers in agricultural education in England and Wales, were amongst the earliest graduates. Somerville subsequently became the first professor of agriculture at three English universities—Durham (Newcastle), Cambridge, Oxford—and three times he established a new university agricultural department. Middleton followed Somerville at Newcastle, Cambridge, and at the Board of Agriculture. As a Development Commissioner and Chairman of the Agricultural Research Council his influence is still powerful in directing the general scheme of agricultural education.

Gilchrist built up the work at Cockle Park over a period of twenty-five years, and Seton developed the unique organization in Yorkshire. Robert Wallace's lectures must have formed the basis of the agriculture teaching at Bangor, Cambridge, Reading, Cirencester, Leeds, Newcastle, and Oxford, and in the matter of 'rediffusion' they probably hold a record difficult to beat.

Up to 1879 little or no consideration had been given to agricultural education by the Government, but two Royal Commissions, one on Agriculture and one on Technical Education, were at work by 1881. The former considered the provision of scientific together with practical instruction, the latter made recommendations dealing with education in rural schools. But in 1886 the Farmers' Club raised the whole question again, and a Departmental Committee, of which Sir Richard Paget was Chairman, inquired into the question of Government grants for Agricultural and Dairy Schools in Great Britain and the administration of such grants. There were then only four

colleges giving courses of instruction in agriculture—those at Cirencester, Downton, Aspatria, and Hollesley Bay—and there was only one dairy school—Worleston, Cheshire. None of them received Government grants. Of these five centres only the Royal Agricultural College at Cirencester still exists, although Cheshire, of course, now has its modern school at Reaseheath.

The Royal Agricultural College at Cirencester is our real link with the early days of systematic agricultural instruction. It has had a unique if somewhat chequered career. It was started in 1845 on lines which would still be approved. It had a large farm on which to provide practical instruction in farm management, and it was the first instance in this country of an agricultural college fully equipped as regards residence, laboratories, and farm for agricultural education as we understand it to-day. But it soon had to give up its farm. Even in those days college farms did not pay, so that with no income other than students' fees the college soon found that its commitments were too great and the farm had to be sacrificed, although, by arrangement with the tenant who rented it, it could still be used for demonstration purposes. This college, however, became a really live centre, and it attracted to its staff many of the leaders in agricultural progress during the last half-century. Unfortunately the college, without endowment income or grants, could exist only with fees at a level beyond the means of any but landlords, estate agents, or big farmers.

The Royal Commission on Agriculture, reporting in 1897, considered that 'if higher agricultural education is to become accessible to any but the comparatively well-to-do, it must be provided by collegiate centres such as those already in receipt of Government aid'.

Cirencester was not included in the rapidly expanding organization of county schemes and advisory centres from 1912 onwards. It lost all its personnel, both students and staff, at the outbreak of war in 1914, and it was not re-opened as an agricultural college until 1922, when a distinguished old student, Lord Bledisloe, was mainly

instrumental in securing a grant from the Government towards the cost of the modernization of the building and its re-equipment. Even then it was not really secure until about 1928, when it became more closely associated with agricultural education in the adjoining counties and with Bristol University. When its work again came under the consideration of a Ministry of Agriculture Committee, of which Sir Daniel Hall was a member, the old college was assisted over its last difficult stile. Since then it has flourished, and has tightened still further its associations with counties and university. It has extended the scope of its teaching, and it has added to its buildings and to the area of land it farms.

It was really during the last ten or fifteen years of the nineteeenth century that public money first became available for agricultural education. In 1886 the Paget Committee advised that, as a completely new system had to be created, it was inadvisable to start hastily—a recommendation which was adopted. But the Committee made some further very valuable and detailed recommendations, including: (1) the establishment of one state-maintained central school principally as a training college for teachers of dairy work; (2) the provision of five district dairy schools in England and Wales, with travelling lecturers for work within each district—they visualized the engrafting of schools of general agriculture on to these centres; (3) pecuniary assistance to other suitable schools established by local effort; (4) an annual grant of £3,000 for research. The Committee also gave its general approval to schemes suggested for the establishment of schools of general agriculture with experimental farms attached in most, if not all, counties—an early blessing on the later farm institute scheme.

As a result of these recommendations, a sum of £5,000 was placed at the disposal, first, of the Agricultural Department of the Privy Council, and later, of the Board of Agriculture, which was set up in 1889 and empowered to aid and to inspect agricultural education.

At that time, fifty years ago, there were no County

Education Committees, no Public Authority charged with providing secondary education of any kind. But under the Technical Instruction Act of 1888, local authorities were empowered to provide technical instruction, including instruction in agriculture. Little was done, however, in most counties until 1890, when the Government imposed additional duties on beer and spirits, intending to use the proceeds partly in grants to local authorities for police purposes and partly as compensation for the extinguishment of liquor licences. These proposals aroused such opposition that they had to be withdrawn and other purposes found for what became known as the 'whisky money', about £750,000 a year.

The money was paid into Local Taxation Accounts for distribution to County Councils who were authorized to use it for technical, including agricultural, instruction. There was no obligation on County Councils to do this, and by some it was merely used in relief of rates. Rather more than 10 per cent. of it, however, was applied for agricultural instruction.

Up to the end of the War the 'whisky money' was taken into account by the Board of Agriculture in assessing grants to County Councils for agricultural education, but after 1919 it was no longer considered as part of the Exchequer grant, and the percentage system, as still used, was adopted instead.

About 1890 many counties set up Technical Instruction Committees which, in addition to developing schemes of their own, supported financially agricultural colleges or universities which provided teaching in agriculture. During the next twenty years about twelve such centres of higher agricultural education were established. In addition, county farm institutes were set up at Basing, in Hampshire, in 1889; Chelmsford, Essex, in 1893; Hutton, Lancashire, in 1894; and Newton Rigg, in Cumberland, in 1896. But the main developments were those at colleges and universities.

Out of the Government funds available in the first year only £2,930 was awarded in grants, and of this only £1,630

in England and Wales. The University College of Bangor received the first grant, £200, in the year 1888–9. The following year its grant was doubled and £4,585 was spent. In 1891 Leeds University received its first grant of £50, and in 1891–2 Newcastle and Aberystwyth were first aided from Government funds. In the following year Cambridge was included, and in 1893–4 Nottingham and Reading appear. By the year 1894–5 the South-Eastern Agricultural College, at Wye, was included, and the total expenditure on grants was £7,850.

Grants for college and university farms began in 1896–7, with some assistance to Northumberland for Cockle Park, followed by grants towards costs of farms at Bangor, Wye, and Leeds. Then came help to Newton Rigg, Uckfield, Holmes Chapel, and Long Ashton, with further assistance for the farms at Reading and Aberystwyth, a grant to the Institute at Chelmsford, and help for Forestry at Bangor and Newcastle. The grants had grown from £2,930 in 1888 to over £10,000 in 1904.

Most of the local authorities financed and relied on extension work from the colleges. Indeed, in several instances the whole of the work, with the exception of some itinerant instruction in such subjects as dairying, horticulture, and a number of manual processes, was done by the local teaching centre. These centres paid particular attention to extension lectures, demonstrations, and experimental work on their own farms, where these were available, and on private farms. They also undertook general advisory work, and were equipped with laboratories and staff to carry out analyses in connexion with it.

Northumberland County Council, in 1891, made a grant of £500 a year to found a Department of Agriculture at what is now King's College, Newcastle-upon-Tyne (University of Durham). Somerville was the first head of this department, and within a period of five years he had forty-six experimental centres in the counties of Cumberland, Durham, and Northumberland—these comprised 817 plots on a total area of about 90 acres of land.

In 1896 Northumberland County Council rented Cockle

Park and provided a centre at which Somerville and his successors at Newcastle could concentrate demonstrations and research—an arrangement that still stands. Most collegiate centres, however, had their own farms, which they developed partly for teaching and partly for experimental purposes.

The developments in the Eastern Counties were centred on Cambridge, which set up its Department of Agriculture in 1899, although the teaching of agriculture had begun five years previously. Here, too, Somerville was the first professor, and he developed that side of the work which provided direct assistance to the counties, thus paving the way for the present-day advisory service.

The developments in Yorkshire were rather different, in fact they were unique for England. The three Ridings combined, and through a Joint Council for Agricultural Education they established an organization, with Leeds University as its centre, responsible for all agricultural education in Yorkshire. The head of the department acted also as County Organizer, and the three County Councils financed the work through the University.

This organization undoubtedly had many advantages—it avoided overlapping and made for economy in many directions. It succeeded in Yorkshire because the danger of over-centralization in agricultural education was realized by experienced members of the Joint Council. The work, to be successful, depends so much on close contacts and a complete understanding on the part of the teacher and adviser of the practical problems on the farm itself—an intimate knowledge of farming practice in the area.

Agricultural work at colleges and university agricultural departments was becoming more systematic. The heads of these departments found it necessary to confer on many aspects of the work, which was broadening all the time. These conferences led to the formation of the Agricultural Education Association.

During this period of twenty years, 1888–1908, the counties, first through their Technical Instruction Committees and later through their Agricultural Education

Committees, began to develop various sides of county work independently of the colleges. Courses of lectures and itinerant dairy instruction, often by means of travelling dairies, were usual methods. It is on record that the practical demonstrations were the more popular. They developed also instruction in bee-keeping, horticulture, poultry-keeping, farriery, and, in some districts, in such work as osier-culture and basket-making. Some counties, e.g. Lancashire, established practical dairying centres and demonstration farms.

In the Midlands, a group of counties took steps to provide central instruction, first in dairying at the Midland Dairy College and later in other branches of agriculture, when the agricultural department at Nottingham was transferred to the Midland College.

In 1893 Essex provided accommodation at Chelmsford with laboratories, and appointed a chemist and a biologist, and developed not only the teaching side but an excellent advisory service. It added school garden work in 1901 and opened the new East Anglian Institute in 1903. Ever since this early start Chelmsford has been a most successful centre in spite of its having no farm. Recently, large developments, including a farm and a new institute building, have been started.

Other counties, such as Cornwall, which has a high proportion of small farms, preferred to decentralize the teaching of science. The instruction was taken to the rural districts, and transport arrangements for pupils were made to selected centres throughout the county. This work, too, has been very successful.

A few counties appointed agricultural organizers during this period, but most of these appointments were not made until the operations of the Development Commission and additional post-War grants made further funds available for agricultural education.

The whole position of agricultural education was reviewed by the Departmental Committee appointed in 1907 under the chairmanship of Lord Reay. This Committee reviewed progress over the twenty years 1888–

1908, and considered that the foundations of a national system of agricultural education had been laid in England and Wales. So far as higher agricultural education was concerned, the Committee considered the number of colleges and university departments adequate, and recommended that further expenditure on that branch should be devoted to improving the equipment at existing centres rather than increasing the number of centres. The Committee felt, however, that any considerable extension of agricultural education would need a bigger supply of well-qualified teachers.

Following on the success of the winter schools and the short courses provided by the colleges, the Committee recommended the setting up of fifty or sixty agricultural winter schools to help to make good what it described as the 'unorganized, unsystematic, and wholly inadequate facilities for agricultural instruction of a lower grade'. Each of these schools, as well as the work of itinerant instructors, should be centred on a farm institute with a farm and other facilities for giving itinerant instructors means of carrying out practical demonstrations. There should also be a close connexion with the local college providing higher agricultural education.

It is of interest that the Committee stressed the need for more attention to milk recording and to methods of milk production.

After suggestions as to the administration of greatly increased grants for agricultural education, the report concludes with two or three paragraphs which are interesting reading thirty years later, and after so many of the recommendations have been, at any rate partly, implemented. We still cherish the hopes of the Reay Committee that improved agricultural education will not only help to make work on the land more attractive and profitable, but will help to maintain a larger rural population in spite of the large exodus of people from the country to the towns during the intervening period. In the meantime, however, and although progress in agricultural education has been more than maintained, the industry

has had to call on Government help of a more direct kind.

The Development Commission was set up in 1909, and new and substantial funds became available for agricultural education. Grants from this fund were restricted to assisting new work. This brought Sir Daniel Hall, first as a Development Commissioner and later as full-time Adviser to the Development Commission, into a position from which he could direct the expansion of agricultural education throughout every phase of its development. In broad outline the scheme now in use is the one planned thirty years ago, although adjustments in details are made as further experience is gained. The rate at which funds could be provided to finance the scheme and the rate at which well-trained recruits became available may not have been limiting factors, but they have set the pace. The Ministry of Agriculture now offers post-graduate scholarships to promising students in agriculture for training in county work.

During the three or four years before the War very considerable progress was made, particularly in the counties and in those colleges destined to become the centres of advisory provinces. There was great activity amongst progressive county committees which were studying methods of organizing classes, providing farm institutes, and developing county schemes based on the provision of county agricultural organizers.

The Development Commission realized that these new county and advisory schemes would need recruits trained in agricultural science in numbers not likely to be available, so, in 1911, Research Scholarships were offered—twelve each year—in the various branches of agricultural science. These scholarships provided three years' training in research, partly in this country, partly abroad, and have been the means of bringing into the service a considerable number of specially trained scientists.

With only three or four exceptions, the seventeen centres for higher agricultural education are also advisory centres

—two of these exceptions are the colleges for women at Studley and Swanley. The teaching work is distinct from the advisory and is financed separately, although advisers are members of the college staffs. Some colleges have provided short courses of six, ten, or twenty weeks for those who cannot afford time or money for longer courses, but these short courses will no doubt gradually disappear as counties become equipped with their own farm schools.

The longer courses prepare students for degrees and diplomas in agriculture; the former usually extend over three full academic years, the latter take six terms spread over two or three years. University departments prepare students for their own pass and honours degrees; they also provide research facilities for those studying for higher degrees. Colleges not affiliated with universities may prepare students for the London external degrees. At some universities specialization is possible in the degree courses, usually in agricultural chemistry, biology, and economics.

Much discussion has revolved round the curricula of university courses in agriculture. Like other applied sciences 'agriculture' is founded on so many pure sciences that there is a tendency to overload the syllabus with introductory pure science subjects, and leave all too little time for that branch of the work comprising 'farm management'.

Generally speaking, the county organizer is the officer responsible for county agricultural education. Practically every county now has an organizer, with a staff of instructors or lecturers stationed at head-quarters or at convenient points throughout the county. Eighteen counties now have their agricultural education centred at farm institutes or schools. Two more farm schools are in course of erection at the present time.

A farm institute or school is now always provided with a farm as an essential part of its teaching equipment. But, in addition, the farm serves as a demonstration and experimental centre for the county. Many counties with no central school have farms for demonstration purposes—demonstrations in connexion with crop or animal husbandry

of particular importance in the county—the 'laboratory' of the county instructors in those subjects. If farmed primarily for profit it may remove all criticism as to the practical ability of the county staff, but if fully used for demonstrating modern methods and teaching young farmers, who actually take some part in the work, it cannot be expected to pay.

A farm school should eventually form the centre for agricultural instruction in each county or group of counties, and it is intended to provide instruction for young people who mean to take up practical farming. At the present time, the numbers who pass through farm schools are exceedingly low compared with the numbers who must eventually become responsible for the working and management of farms. There has been a tendency to lengthen the farm institute courses. The view was held originally that it could best serve its purpose by training boys and girls during that period of the year when they can best be spared from the farms, but the courses provided in some of the most modern schools now extend to one year, and there is much to be said for this arrangement even when the course is divided into various sections, such as general agriculture, dairying, poultry-keeping, horticulture. There is more than enough to keep the students busy for the whole of a year, and it is also desirable that they should see the work of their departments through a full year's cycle. At some schools inadequate hostel accommodation has made it impossible to take students of both sexes at the same time. This has led to six-month courses in agriculture for boys in winter, and dairying and poultry courses for girls in summer. But layout, buildings, and equipment are improving with each new school. The latest, at Durham, opened in October 1938, is exceedingly well equipped and embodies all the experience that could be gained from older schools.

The farm school courses should be complete in themselves and not merely preparatory courses, although selected students may have the chance of more advanced courses later—to some extent they are sure to be recruiting

grounds for men and women who will afterwards train for professional posts in agricultural education. The instruction should not constitute any real break in the continuity of the student's apprenticeship upon his father's or some other farm. They are natural channels through which recruits from other occupations enter farming. The Ministry of Agriculture and most local authorities, including some county boroughs, now offer scholarships for all types of agricultural courses at farm schools, colleges, and universities.

But the teaching of young farmers is only one part of county education. Amongst the developments which took place in county work immediately after the War was the appointment of what were called district lecturers or district organizers. These lecturers were stationed in, and made responsible for, certain portions of the county. Yorkshire was at first divided into areas based mainly on farming systems, the lecturer making his head-quarters at some central market town. At present there are seven such areas in Yorkshire.

It was about 1919, too, that the motor cycle and car first began to influence extension work in agriculture. In the pre-War days an advisory visit to one farm took the whole day wherever it was situated, a train to a wayside station, a horse and trap to meet you, a drive of two or three miles to the farm, a return drive to catch the afternoon train, and so back to head-quarters. Such leisurely travelling had its advantages—it was possible to see a good deal of farming besides that on the farm visited—but it would be impossible to carry out the present-day county duties in that way.

The district lecturers quickly opened up areas hitherto scarcely touched by the more centralized scheme, and the enthusiasm with which they approached the problems in their own particular districts brought an abundance of advisory work, for there is no surer way of getting the ear of the farmer than by discussing his problems with him on his farm. In Yorkshire the method was particularly effective in promoting advisory work on problems of soi

and crop husbandry, in establishing local demonstration plots, especially in connexion with the manuring of grassland, variety trials, and seeds mixtures, and incidentally in providing material for research. The co-ordinated grassland manuring trials carried out by means of the district lecturers laid the foundation of the 'grassland campaign' work in that county from 1920 onwards, and provided valuable information on the treatment of different types of grassland. A later development in Yorkshire was the specially organized day or evening class, set up at a suitable centre in the county, the district lecturer being mainly responsible for the instruction given, together with some assistance from the university. But that is only one instance of many. The appointment of district lecturers has been, perhaps, one of the most successful of the county schemes, and many of the larger counties have now adopted it. The formation of local committees, of discussion societies, and of organized day and evening classes based on these planned districts, has helped to bring together the farmers and young farmers of a particular area for more intimate discussions of farming matters under the guidance of the district organizer.

It will be seen that, as agricultural education develops, decentralization—taking the first stages of agricultural education as near the farms as possible—seems to be the generally favoured and most successful method. Where, as in Devon and certain other counties, particular efforts have been made to utilize the Young Farmers' Club movement, the work among young people has been greatly facilitated. Here is perhaps a very outstanding instance of a movement started without State aid developing into one of the most useful preliminary stages in agricultural education and one which is a fertile recruiting-ground for students entering courses in agriculture. It covers that awkward gap between school-leaving age and the age at which a student usually enters a farm school or a college. Within recent years much discussion has centred on the question of this gap, and here and there efforts are on foot to engage and maintain the interest

of children from school-leaving age up to the age at which they would normally commence systematic courses of agricultural instruction. This gap will no doubt get narrower. One method of reducing it now being tried is to equip central schools in rural areas in a way which will enable them to make the instruction during the last two or three years at school increasingly vocational, but beyond the Young Farmers' Club movement there is no official means of keeping the 15-year-old boy or girl within the general scheme of agricultural education.

Although local authorities have complete autonomy in the matter of agricultural education, the Ministry of Agriculture has at various times initiated special 'campaigns' in respect of improvements in some particular branch of farming. To do this they have sometimes called in specialists to lecture and advise, but the local arrangements for such campaigns have been in the hands of the county organizers. The Improvement of Grassland Campaign began in 1920 and continued until 1925. This was an attempt to improve the grassland of the country as a whole, and by so doing to make it possible to keep much of the land ploughed out under the 1917 Act under arable crops. Special lecturers were appointed to address meetings of farmers and to visit grassland areas and suggest methods which might be demonstrated by means of experimental plots. By the end of 1921 it looked as though the main object of the scheme would be completely swamped by economic circumstances. In fattening areas grass was the last subject farmers wished to discuss. Nevertheless, in 1924 and 1925 over 800 series of plots were in existence in England and Wales, and all recognized methods of grassland improvement were included. The subject was discussed at length at the Agricultural Organizers' Conference, at Oxford. Other local conferences on grassland improvement were also held up and down the country. This activity in grassland research has never diminished, and some counties have at various times included the competition method of drawing farmers' attention to the possibilities. Northumberland, Cumber-

land, Hereford, Radnor, and Brecon are amongst the counties which held Pasture Competitions. Practically every county has given some attention to grass, and now, twelve years after the previous campaign and owing mainly to very active research which is throwing new light on many problems, a campaign is again in progress aiming at rectifying the condition of much grassland believed by many to be more unproductive than in 1914.

Another campaign started about 1924, as the result of work on clean milk production at Reading. It has spread to every milk-producing county, and to some in which milk is a secondary consideration. It has gathered strength and become such an important county scheme that many County Councils have added assistants in dairy farming to their agricultural staffs. The method adopted at first was the competition, supported by advisory work. Reading at first undertook most of the bacteriological examinations of milk, but later, when clean milk competitions attracted large entries, the samples were examined at the local advisory centres. Certificates of efficiency were given to competitors who had maintained a satisfactory standard. This work made heavy calls on the time and energy of members of county staffs. Sampling and advising had to be done at milking time, including morning milking. Essex conducted the first county clean milk competition, from Chelmsford, in 1920, and held one every year thereafter until the Accredited Milk Scheme started.

Then came all the advisory work in connexion with designated milks. As a result of the Reading work, many farmers in that district had eliminated tuberculosis from their herds and adopted methods for producing milk of a high standard of cleanliness. These producers pressed for some official recognition of this high-grade milk from the Ministry of Health.

Under the Milk and Dairies Amendment Act, 1922, the Milk Special Designations Order, 1923, authorized the grading of milk as: Certified; Grade A; Pasteurized. An additional grade known as Grade A (T.T.) was added for the benefit of those producers who sold milk from

tuberculin-tested herds, but did not bottle it on the farm. These grades were confusing to the consumer, so that, later, with assistance from the Empire Marketing Board and under the new Milk Special Designations Order, 1936, the system of grading was simplified to: Tuberculin Tested; Accredited; Pasteurized. Responsibility for these orders rests now with the Ministry of Health, through the Local Authority. One of the main difficulties in keeping up supplies of T.T. milk is obtaining adequate numbers of non-reacting cows and heifers. To meet this difficulty the Ministry of Agriculture has provided assistance in the building up of herds entirely free from reactors under the Attested Herd Scheme.

The duties of county organizers under the graded milk schemes vary from county to county. In some they act purely in an advisory and non-official capacity, in others they report on the suitability of buildings, equipment, and methods, to the appropriate department of the licensing authority.

Apart from these national and, to some extent, co-ordinated schemes, developments in the counties have shown both independence and originality. Wiltshire, for instance, has so developed its advisory work through district organizers and published advisory leaflets that the education service claims to be in direct touch with all of the 3,000 farmers in that county. Amongst original schemes in this county are: the Wild White Clover Certification Scheme 1929, the County Register of Accredited Milk Producers 1929, the County Pig Recording Scheme 1930, and an Agricultural Accounting Society begun in 1925, soon after the appointment of the Adviser in Economics at Bristol.

East Suffolk, with full realization of the value already obtained from the Saxmundham experimental station started in 1899, tackled a second large land fertility problem in 1926 when it established a second experimental station at Tunstall on light, acid land at the opposite end of the scale from that at Saxmundham. Later, in 1936, this led the county organizer to initiate a lime survey, an

experiment which was of great assistance in the development of the Government's Land Fertility Scheme in 1938.

In connexion with live stock, R. Boutflour's work on the rationing of dairy cows was officially recognized by his appointment to a newly created post of Director of Dairy Husbandry at Harper-Adams College. For about five years he lectured and demonstrated to farmers and milkers in almost every county.

Again, W. A. Stewart, with facilities at the farm institute in Northants., has done valuable work on the breeding and feeding of bacon pigs. At the Hertfordshire Farm Institute, Hunter-Smith is developing methods of selecting dairy bulls of potentially high milk-yielding strains.

There is also the Land Fertility Scheme, with Government assistance for the purchase of lime and slag. In spite of the extra field and laboratory staff provided at advisory centres, much of the sampling and subsequent advisory work has fallen, in most counties, to the lot of the county agricultural staffs.

County agricultural organizers played a lone hand at first, and had to organize an office staff to deal with an ever-increasing volume of correspondence from official sources and from farmers; but being at first the only members of the agricultural education staffs trained in agriculture, they had to divide their time between office and committees and the practical side of the work on the farms.

They usually had on their staffs instructors in dairying, horticulture, and poultry husbandry, but only gradually were they able to get assistance for farmers' lectures, demonstrations, and experiments to test new ideas and give guidance in advisory work which was increasing so rapidly. Office—committees—advisory work—evening lecture or meeting of farmers or organized classes, may be said to constitute the average day of the organizer. But it has had its reward in its influence on farm practice. Improvement in the use of fertilizers, the balancing of livestock rations, the management of live stock, the production of milk, methods of crop husbandry in counteracting

diseases and insect damage is sufficient evidence of the effects of the spread of agricultural education throughout every county.

The rapid expansion in the work of county organizers has brought out the need for regular discussions of their work amongst themselves. For some years Agricultural Organizers' Conferences have been held every second year, alternately at Oxford and Cambridge. More recently (1938) the Association of County Organizers of Agricultural Education has been formed.

The development of advisory and experimental work within the county might have weakened the sphere of influence of the central college or university in the province, had it not been counterbalanced by the establishment of advisory centres. The Board of Agriculture met 'the necessity for remodelling and materially strengthening the advisory side of the work undertaken by the staff of the greater number of institutions aided by them' by setting up 'advisory provinces' consisting of groups of counties with an advisory centre—either a college or university agricultural department—for each.

The object was to provide a technical adviser, a specialist in his own particular subject, with full laboratory facilities to undertake the investigation of local problems in connexion with soils, manures, feeding-stuffs, pests and diseases, economics, diseases of live stock, and dairying—in fact to help the county staffs and the farmers over any technical difficulty. Further provision was made to keep advisers and organizers in close touch with the national research institutes, which were being established at the same time, so that bigger problems involving fundamental and probably lengthy investigation could be dealt with.

No attempt was made to start the scheme at what was intended to be its full strength. It was a completely new venture, experience was needed, but most important of all it was difficult to find enough men qualified for research in the various branches of science, and sufficiently

experienced in agriculture, to undertake independently the investigations needed. Time was necessary to train suitable men, and the Development Commission was providing funds—scholarships—for such training.

Before the outbreak of war twenty advisory officers were appointed. Had not the War intervened the full complement would have been reached probably by 1916. The first appointments were in chemistry, mycology, and entomology.

In 1922 the Development Commission approved a scheme to bring the number of advisory officers up to thirty-five, distributed among thirteen centres. Of this total twenty-six were mycologists and entomologists, the reason for this preponderance being that these two subjects had received, on the whole, less attention than agricultural chemistry.

The need for local facilities for the study of the business side of farming, farm accountancy—the 'science of farming'—led to the appointment of advisory economists. The first four were established at Leeds, Cambridge, Reading, and Wye in 1923, according to a programme drawn up at Oxford. There was still greater difficulty in finding the right people for agricultural economics than for chemistry or biology. But post-War conditions emphasized the need for sound advice in farm accountancy. A. G. Ruston's work in Yorkshire was an outstanding example of direct assistance to farmers in a subject vital to the success of a farm. His help to the young farmers newly returned from the War, who had put all they had into farms, often badly under-capitalized for the times, and who felt the full brunt of the crash in 1921, will long be remembered by many. Some could never have won through without that help.

Although some colleges had given attention to veterinary hygiene previously, the filling of advisory posts in veterinary science—as in agricultural economics—was started slowly, partly through lack of funds, but partly to give time to see how the experiment answered. The Ministry of Agriculture was considering certain of these

appointments in 1921, and the first appointment of an adviser in veterinary science was made at Cardiff in 1923. By 1928, however, only three more had been added, at Bangor, Newcastle, and Liverpool (Manchester Province). Then followed appointments at Bristol and Harper-Adams in 1929–30; Seale-Hayne and Wye in 1930; The Midland College, Cambridge, and Reading in 1931, making the present total of eleven. The title was subsequently changed to Veterinary Investigation Officer to prevent any misunderstanding as to the relative functions of these officers and veterinary surgeons in private practice.

The appointment of dairy bacteriologists was mainly due to Stenhouse-Williams's work at Shinfield on bacterial contamination of milk. He had not only investigated the main causes of contamination, but had worked out methods of estimating the degree of contamination of different kinds, and practical methods of converting buildings and providing dairy equipment to facilitate the production of 'clean milk'. Stenhouse-Williams had applied his routine methods for the examination of milk to samples from private farms, and had encouraged the 'competition' method of introducing his methods to dairy farmers and their workers. Local authorities continued this with support from the Ministry of Agriculture. Wiltshire began clean milk competitions in 1924, and asked the advisory centre (Bristol) to undertake the routine examination of milk samples, the judging of methods on the farms, and some of the advisory work arising therefrom. This led to the appointment of a dairy bacteriologist in 1924, and in the same year bacteriologists were added to the advisory staffs at Cambridge and Wye.

In 1924 the advisory service as a whole comprised fifty officers. By 1932 there were seventy-three advisory officers, and there are about eighty-four at the present time (January 1939).

The total expenditure by the Ministry of Agriculture on advisory services was £1,568 in 1912–13, £22,930 in 1922–3, £69,795 in 1932–3, £86,815 in 1937–8.

The thirteen centres to which groups of counties are allocated are:

Aberystwyth . . .	Mid-Wales.
Bangor	North Wales.
Bristol	Gloucestershire, Herefordshire, Somerset, Wiltshire, Worcestershire.
Cambridge . . .	Eastern counties.
Cardiff	South Wales and Monmouthshire.
Harper-Adams College .	Shropshire, Staffordshire, Warwickshire.
Leeds	Three Ridings of Yorkshire.
Manchester . . .	Cheshire and Lancashire.
Midland College . .	Derbyshire, Leicestershire, Lindsey, Kesteven, Nottinghamshire, and Rutland.
Newcastle (King's College)	Four northern counties.
Reading	Berkshire, Buckinghamshire, Dorset, Hampshire, Middlesex, Northamptonshire, Oxfordshire, Isle of Wight.
Seale-Hayne College .	Cornwall and Devonshire, Isles of Scilly.
South-Eastern Agricultural College . . .	Kent, Surrey, and Sussex.

These advisory centres[1] are fully equipped for the work of specialist officers in agricultural chemistry, mycology, entomology, economics, veterinary science, and dairy bacteriology. Most of them are attached to teaching centres, but the amount of teaching which advisory officers may undertake is, by agreement with the Ministry, strictly limited. Their main duties are to provide assistance and advice within the province and to investigate local problems as they arise. Few counties have complete laboratory facilities and trained staffs for carrying out analytical or investigational work, but county organizers may call upon the advisory centres for help in the solution of problems arising from farmers' inquiries.

[1] All except one or two centres have the full team.

Of the advisory services, that in agricultural chemistry is the oldest; every advisory centre, except Cardiff, had its chemist by 1929–30. Advisory work in connexion with soils, fertilizers, and feeding-stuffs had always been undertaken by the colleges. There was a large demand for analyses of such materials; the information was necessary to the advisory work of the agricultural staff and to much of the experimental work of the centre. Advisory chemists, however, have had to put a check on requests for analyses from the merely curious, those anxious to know whether a fertilizer or a feeding-stuff conforms to its guaranteed analysis, and other similar requests, including those likely to lead to litigation. In general, analytical work is undertaken only in cases where it is essential to the elucidation of problems on which advice is sought.

For over twenty years the service has been well established, and advisory chemists have met once or twice annually to discuss the main aspects of their work and to arrange for the necessary co-operation in problems which affect more than one province. At the present time, representatives of the Agricultural Research Council, Land Fertility Committee, and the Rothamsted Experimental Station attend these conferences, for advisory chemists have matters in hand of direct interest to these bodies; these matters include artificially dried grass, lime and phosphate status of soils, and crop troubles due to what are apparently deficiencies in 'minor elements' such as boron and manganese.

Advisory chemists soon found, amongst the problems recurring on individual farms, questions of outstanding interest and importance to their own provinces; amongst these was the problem of soil acidity, and its related problem of lime-supplies. In several of the earlier conferences a great deal of time was occupied by discussions of this subject and in working out co-operative schemes for investigating it. In certain areas, such as West Yorkshire and East Lancashire, the smoke problem gave ever-increasing trouble and emphasized the importance of liming. So acute was the soil-acidity question in York-

shire that for some years most of the advisory chemist's investigational work was concerned with that problem. The ploughing-out orders under the Corn Production Act, 1917, left a long trail of acid, infertile, ploughed-out grassland to bring back into cultivation, and over a large portion of the county there were relics of ploughed-out grass which could neither be cropped nor put down again to grass.

At other centres special interest has been taken in soil surveys, and efforts made to develop this work and produce maps that will be of use to county organizers and farmers and will systematize advisory and experimental work on soils. G. W. Robinson (as chairman) and Morley Davies (as secretary) of the Ministry's Soil Survey Conference have been largely responsible for this work in England and Wales, where such surveys seem likely to develop into an important function of the advisory centres.

In 1938 the Government's Land Fertility Scheme brought an enormous amount of soil work to the chemist, who is primarily responsible for all the analytical work on soil samples submitted by county organizers, and is also responsible for producing maps indicating the lime status of soils within his province. All centres have been provided with extra assistants for the laboratory and field work involved in systematic, field-by-field surveys of selected areas. Such large-scale work, requiring large numbers of determinations of 'acidity' and 'available' phosphate and potash in soils, demands quick laboratory methods which are not always forthcoming. The laborious and lengthy methods for determining 'availables' in soils impose a serious limit on the numbers of samples that can be analysed. Co-operative work is arranged, however, through the advisory chemists' conference, for revising methods of analyses with a view to discovering and adopting quicker, more convenient methods.

Immediately after the Armistice new problems arose through changes in types of phosphatic fertilizers. Gradually mineral phosphates were becoming popular for use on grassland, mainly owing to results obtained at Cockle

Park, and basic slags had changed with the adoption of new methods at the steelworks during the War. This led to further collaboration of advisory chemists on methods of comparing the mineral phosphates from various sources, and the new types of basic slag, with types formerly in use.

On the question of nutrition, advisory chemists have given much attention in recent years to the quality of grazings. At Aberystwyth a great deal of information has been obtained on the nutritive value of different species of plants, especially as to mineral content and changes in nutritive value with growth. At Newcastle a detailed examination has been made of the herbage of uninclosed grazings, and especially of those plants other than grasses on which sheep seem to rely at certain times of the year.

The position as to advice on the control of diseases and pests has changed completely since the advisory mycologists and entomologists were appointed over twenty years ago. From the beginning these officers have kept in the closest touch with the Ministry of Agriculture's Plant Pathology Laboratory, at Harpenden, and with each other; through the Director they have established a very complete intelligence service. By means of monthly reports all advisers are kept informed of outbreaks of disease or of damage by pests. In addition, advisers hold two conferences each year, one in London, one in the provinces. Annual reports from each advisory province are circulated.

The rapid increase in the production of fruit, vegetable, and flower crops in recent years has naturally provided mycologists and entomologists with a great deal of work. Apparently there has been a greater need and certainly a greater scope amongst such crops. Mycologists, however, have paid much attention to diseases of cereal and root crops, and especially potatoes. The work on the control of virus diseases in potatoes is perhaps one of the most outstanding features of the period under review.

In addition to their annual report, the advisory entomologists prepare annually a list of pest troubles coming

under notice during the year. The list at present consists of over 150 pests spread over 12 groups of crops.

Entomologists, too, have found great scope amongst horticultural crops, but the problems are no less important in more extensively cultivated farm crops—wire-worms and leather-jackets, frit-fly and turnip flea-beetle still take heavy toll in certain seasons. New crops bring new problems—sugar-beet is one example—and control measures must be tested and demonstrated locally. Knowledge of local conditions is of great importance in dealing with pests and diseases; the advisory system for mycology and entomology has, by its complete co-ordination, placed all available means at the disposal of the provincial officer and through him at the disposal of the farmer too.

The present advisory service in agricultural economics is a post-War development. During the War the Ministry of Food set up an Agricultural Costings Committee in connexion with the control of food prices; the Committee reported on costs of milk production in 1920. The collection of data for this work was done by district officers having no connexion with agricultural education. In 1919 and 1920 the Costings Committee discussed with representatives of agricultural colleges and universities the possibility of continuing to record accurate and detailed costs on selected farms, and of encouraging farmers to keep less detailed accounts for themselves. The college representatives, however, were suspicious of the uses to which the figures were to be put, and decided to stand aside as long as the objects were not purely educational. The 1920 conference passed this resolution: 'That this Conference is of the opinion that the chief advantage to be derived from Farm Costs is as a means for improved farm management. That the conditions affecting farm management are largely local, and that therefore the local collection and analysis of farm costs and the advisory work arising therefrom should be under the direction of and carried out by the Agricultural Colleges.' However, after 1921 the Ministry of Food took no further responsibility for the Costings Committee and it ceased to exist.

It was left to the Ministry of Agriculture to take over the costings work in its educational aspects. Hall was responsible for starting the ball by promising official consideration of any scheme put forward by the colleges for introducing farm costings as an aid to the study and teaching of farm management. Hall's great contribution was the emphasis he placed on statistical records. He was convinced of the value of a scientific study of the business side of farming supported by recorded evidence and replacing rule-of-thumb methods. It will be noted that stress has been laid on 'costings'. C. S. Orwin had worked out details of farm costings based on factory practice of accounting, department by department. The first work of the newly appointed advisory economists was mainly costings. But rather more faith had been placed in farm costings than was subsequently justified; the effort was rather disproportionate to the results. More ground has been covered by other methods, such as extracting data from a larger number of farms for one particular enterprise without costing the whole farm. The three main lines of investigation now are: (1) the originally planned full farm costings; (2) enterprise studies; (3) surveys.

In 1924, at Bristol, in addition to full cost accounts for a few farms, simple accounts were kept for several groups of farms of similar types and studies made of the important enterprises on such farms. Farmers met and discussed their accounts. This led to the formation of the Wiltshire Farm Accounting Society, which has now been in existence for fourteen years. Poultry and milk have also formed subjects for enterprise studies in which two or more provinces have collaborated. Some of these enterprise studies, such as Cost of Milk Production, have been placed on a national basis, in this case financed through the Ministry of Agriculture by the Milk Marketing Board. Surveys, such as the one in East Anglia conducted from Cambridge, have been undertaken in several districts. A farm management survey is also conducted in all provinces as part of a national co-ordinated investigation into farming trends.

Suitably trained men were so difficult to find at first

that advisers were provided with student assistants trained in agriculture or economics or accountancy to help with the investigations and at the same time gain experience of the work. Usually two assistants were provided at each centre. These posts were, however, too temporary to ensure the necessary continuity in the work, so that in addition to the student assistants each centre is now provided with a permanent technical assistant, generally some one trained in economics.

Although originally much stress was laid on the importance of decentralizing farm costings, the tendency at present is to make use of the advisory economist and his staff for co-ordinated national schemes. Developments under the Marketing Acts have provided openings for men trained in these services, and opportunities for making use of material from some of the enterprise studies and surveys.

The establishment of the veterinary advisory service naturally gave some concern to practising members of the profession, but the officers appointed soon made it clear from their work that there was no conflict of interests and that these appointments were actually in the best interests of agriculture and the veterinary profession. Their main lines of investigation are in connexion with diseases of long standing causing serious losses to farmers, diseases which have not hitherto yielded to investigational work and on which existing information is very imperfect.

Apart from a good deal of assistance to farmers in freeing herds from diseases such as Tuberculosis and Contagious Abortion, research work has been developed largely in connexion with poultry and sheep diseases. At one or two centres, e.g. Bristol, special officers have been appointed to deal with poultry diseases, whilst at other centres, such as Bangor and Newcastle, local funds have been made available to augment the advisory grant for research on sheep diseases.

So important is sheep-disease work in the northern counties, especially Northumberland, that a committee appointed to administer the Alan Duke of Northumberland

Memorial Fund has for some years devoted these moneys to research into sheep diseases. The committee has also collected annually a substantial sum in subscriptions from landowners and farmers in the province towards work on 'border pining', various lamb diseases, and tick-borne diseases. These investigations are in the hands of the Veterinary Investigation Officer, W. Lyle Stewart, and the funds have made it possible to provide a bio-chemist to assist him. Quite recently local authorities have agreed to contribute towards a large-scale 'tick' experiment. The Adviser prepares annual reports on the progress of such investigations, and these are published by the Committee and distributed amongst sheep farmers and subscribers to the fund. Much of this work is done in the closest collaboration with the Ministry's veterinary laboratory, at Weybridge, and with members of the North of England Veterinary Medical Association.

Dairy bacteriologists were added to the advisory service when county education in clean milk production extended beyond the bounds of the Reading province. Although for a time Reading undertook the examination of milk samples on behalf of county organizers and farmers, as soon as clean milk competitions were in full swing the number of samples was enormous, and the time taken for samples to reach Reading from distant provinces was too long. Newcastle, as a provincial centre, organized a clean milk competition in 1924, the examination of samples being undertaken by the Professor of Bacteriology in the Medical School. The experiences gained during that competition, however, made it obvious that the control of sample testing and the provision of advice in bacteriology based on these tests required a full-time officer, and before county organizers in the northern province initiated competitions in 1925 a bacteriologist was appointed at New-castle. At Bristol the appointment was hastened by the large entries in the Wiltshire clean milk competition.

For some time the bacteriologists were mainly concerned with competitions and the advisory work necessarily arising from them. Their services were also utilized

by county staffs in tracking down sources of trouble on producers' premises and in tracing unusual faults in dairy products. But in most provinces the advisory officer has now established relationships with producers and with local authorities, whereby he examines milk samples at regular intervals or as required, and makes use of the results for advisory purposes. At some centres samples from official sources are not received at all, at others the adviser accepts samples submitted by the authority supervising milk supplies, but only in an advisory capacity; no official action is taken on the results of his tests beyond suggesting to the producer that advice is needed and can be obtained. These methods have, on the whole, been very successful.

Dairy bacteriologists hold conferences twice annually at which co-operative experimental work is arranged and methods of examining milk standardized.

Special courses are arranged at intervals for sanitary inspectors, milk-distributors, and others upon whom the quality of the local milk-supply depends. Usually the courses for sanitary inspectors are held at the advisory centre and are well attended, but occasionally courses for others interested may be arranged at other institutions such as technical schools, when the dairy bacteriologist usually gives part of the instruction.

Provincial Advisory Conferences are held regularly, in most provinces, to enable advisers and members of the college and county staffs to discuss the proper co-ordination of agricultural education within the province. Sometimes this arrangement has been taken a stage farther, and joint meetings for two adjoining provinces have been arranged, or information exchanged between two provinces, through the conference secretaries.

The Ministry of Agriculture has itself within recent years played a leading part in certain aspects of agricultural education, and more particularly in helping to bring home to the farmer the usefulness of the service it provides in counties and in the provinces. It has developed a publication service which is of great value in that it

provides in a cheap but attractive form up-to-date information on almost every subject, set out in a manner easily understandable by the practical man.

Agricultural education exhibits at agricultural shows, both national and local, have long been one means of drawing farmers' attention to the educational work. In the smaller local shows the county organizer is usually responsible for the educational exhibit, and is supported by members of the staff of the local college and advisory centre, but for large national shows, including the Royal Show, the Bath and West and Southern Counties, and the Royal Welsh Show, the Ministry has now developed a method of assisting which has enabled them to provide larger and more uniformly staged exhibits.

On three occasions within the last twenty years the Ministry has actively supported, by educational methods, the development of instruction in crop husbandry—in 1920–2, in 1924–5, and again in 1938–9. So far as live stock is concerned, the Ministry has also financed and supported schemes for the improvement of all classes of live stock, not merely the larger live stock through the premium sire schemes, but also smaller live stock by such schemes as that promoting the distribution of sittings of eggs. Similarly, the Milk Recording Societies are assisted by the Ministry.

Progressive commercial firms dealing with the manufacture and distribution of agricultural materials, such as fertilizers and feeding-stuffs, have for many years employed agriculturally trained advisers. In addition to the demonstrational and experimental work undertaken by the firms themselves, they have generously assisted in many ways the work of the various authorities concerned with agricultural education, usually directly but sometimes through joint committees on experimental work (such as the Permanent Committee on Basic Slag) which operate through the Ministry of Agriculture.

During the last forty years the attitude of farmers and farm workers towards education and research has changed

completely—their confidence has been won. The National Farmers' Union gives its full and active support.

The soundness of the scheme as a whole is proved by its progress and by the fact that very rarely has retraction been necessary. It associates the farmer, through the county organizer and the provincial advisory centre, with the research worker. It is co-ordinated by the Ministry of Agriculture, with an inspectorate in the provinces and commissioners for special branches, such as dairying, horticulture, and poultry husbandry, at Whitehall Place. The Ministry finances the work of local authorities to the extent of 60 per cent. of approved expenditure. So far as agricultural colleges and university departments of agriculture are concerned, the Ministry bears the whole cost of the provincial advisory scheme and assists the general teaching work by means of block grants assessed quinquennially.

As the scheme moves on towards completion—it still has a long way to go—and as each local service grows, efficiency requires most thorough and loyal co-operation between college and county. On that the success of this most comprehensive system does undoubtedly depend.

THE ART OF HUSBANDRY

By J. A. SCOTT WATSON

'The best doung for ground is the Maisters foot, and the best provender for the house the Maisters eye.'

ON a day in December 1837 the third Earl Spencer, one time Chancellor of the Exchequer, was addressing a meeting of the Smithfield Club in London. It had recently occurred to him that the formation of a National Agricultural Society for England might result in important benefits to the country, and he took occasion to submit the idea for the consideration of his fellow farmers. Certain branches of science had begun, he said, to make notable progress, and it must seem that the farmer could no longer afford to ignore their possible applications to his business. The English farmer had not yet attempted to apply Science to Practice; but numbers of scientific experiments had already been carried out, and if only their results could be made intelligible to practical men 'an improvement might soon take place that few had any conception of'.

Spencer was right in his appreciation of the hour; true science was just beginning to be brought to bear on the farmer's problems. The association of Lawes and Gilbert, which was to prove so fruitful of results, had already begun. Within two years Liebig was to set out clearly the known facts about plant nutrition and to map out the field of future research. The first clumsy steam plough had already turned an awkward furrow.

Moreover, it can hardly be said that Spencer set his hopes too high; the following hundred years were, in fact, to see notable changes produced by the application of science to the 7,000-year-old craft of farming. And yet if we read contemporary accounts of the best English farming of those days we may well be astonished at what could be done without the aid of science; and if we survey the industry as it is carried on to-day we shall probably

conclude that traditional knowledge and craftsmanship still count for more than the application of science.

In the early volumes of the *Journal* that Spencer's new Society began to publish are papers by John Grey on the agriculture of Northumberland[1] and by Philip Pusey on that of Lincolnshire.[2] The farmers whose systems are there described knew nothing of the hydrogen-ion concentrations of their soils, yet they understood pretty well the value and use of lime. They knew nothing of phosphates, but they had seen how bone manures could increase the yields of turnips and clover. Half a century was to pass before a bacteriologist was to set eyes on *Bacillus radicicola*, yet those farmers knew, as other farmers had known two thousand years before, that clover root was an excellent manure for wheat. Moreover, all this knowledge had been woven into a tapestry which could show rich crops of corn and great flocks of fattening sheep upon a landscape where, a few years earlier, the sheep had been few and scraggy and the background a wide stretch of heath and moor.

Spencer chose *Practice with Science* as the motto of his new society and evidently hoped for a speedy marriage of the pair; but the wooing was to be protracted, and often unhappy. The practical man had long learnt to distrust the book farmer, and could hardly have been expected to distinguish the new species from the old. Moreover, some of the exponents of the new knowledge were over-confident of its worth, and too ready to belittle the value of the accumulated experience of two hundred generations of farmers. Even the great Liebig was to over-simplify the problem of feeding the plant, and was to make one major and fundamental mistake; and supposing that the real men of science had walked always with proper caution, the pseudo-scientist and the quack would have remained to provoke the ribald mirth of the man on the land.

But all this is by way of becoming an old tale. If there are still farmers who are hide-bound by tradition, and

[1] *Journal of the Royal Agricultural Society of England*, vol. ii (1841).
[2] Ibid., vol. iv (1843).

unreasonably suspicious of 'theory', there are others who are too ready to apply every new idea and adopt every ingenious invention. If there are still men of science who chase wild geese, there are others so obsessed with the complexity and difficulty of the practical problem that they are afraid to tell the farmer how to feed his pig. In general, the farmer and the man of science are each the willing pupil and unpretentious teacher of the other; moreover, there are numbers of people—county organizers and others like myself—who are trying, with fair and increasing success, to reconcile, and fit together into one piece, the new knowledge and the old.

When we ask ourselves how much of our modern farming has become applied science and how far it remains a traditional craft, we find that our answer must depend on the particular branch of farming that we have in mind. One problem of practice may have proved to be simple, in terms of modern science; another may have been found to be immensely complicated. The modern dairy farmer, for instance, if he is to produce milk at a profit, must either himself understand something of the chemistry of foods and the principles of nutrition, or else must rely for the essential knowledge on his county organizer, or on the merchant who compounds his dairy cake. It may be that our knowledge is still small by comparison with our ignorance; but science has given us a system of cow-feeding which is simple enough to be applied in the cow-shed, and which is an important improvement on anything that the cow-feeder could conceivably have worked out for himself.

On the other hand, one cannot promise the dairyman that he will be enabled to put much money in his pocket by devoting five years of his leisure, if he has any leisure, to the study of genetics. The geneticist may, indeed, explain to the breeder, in terms of the laws of the combination of genes, why he should find it so difficult an affair to breed a 2,000-gallon cow or to select a stock bull that will raise the average production of his herd. Science may warn the farmer against too sanguine hopes, and may urge

upon him that a small trial may save him from an important error. But the recipe for success in breeding is still an ounce of science to a pound of intuitive judgement and half a stone of luck. Our system of milk-recording is based on practical common sense rather than on the scientific principles of heredity. So also is the practice of progeny tests. Bakewell, although he would not have understood the phrase 'genotypic selection', was applying the principle long before Darwin and Mendel were born.

A parallel contrast may be drawn between the science of fertilizers and the art of tillage. We have said that the old farmer realized the value of lime; but he had no quantitative measure of the lime requirement of his soil and we know that he must often have spent money needlessly by erring in the direction of generosity, and even by applying lime where none was needed. There is an old pit in Berwickshire that must have yielded, during the latter part of the eighteenth century, some thousands of tons of supposed marl which (according to the writer of the County Survey) contained no more than a trace of lime. The old farmer, again, knew the value of bone manures; but when the supply of bones showed signs of giving out he did not know where to turn for a substitute. Liebig and Lawes had to tell him. A hundred years ago the first experiments with Chilean nitrate showed that this substance often produced a remarkable increase in the yield of wheat and yet, inexplicably, failed to answer as a manure for clover.

A handful of chemists with their test tubes, pot experiments, and randomized blocks have, in a hundred years, found out far more about the nutrition of the plant than many millions of farmers in fifty or a hundred times as long. There are, indeed, some who believe (so far as I can understand them) that there is something rotten in the state of this branch of science; that the chemist has ignored some fundamental principle of soil fertility which may, indeed, be hard to define but which, at any rate, has nothing to do with the abundance in the soil of what the chemist regards as the elements essential to plant growth;

and that artificial fertilizers are a snare and a delusion, doing no more than to conceal, for the time being, the disastrous depletion of the essential goodness of the soil. But my flesh refuses to creep. No doubt we are discovering, as we keep making good the grosser deficiencies of our soils, that the 'minor elements' can assume more than minor importance in plant nutrition. No doubt an interesting and conceivably important field of inquiry has opened up with the discovery of organic growth-promoting substances. No doubt many other discoveries remain to be made. But all this does not alter the fact that we have now so large a body of scientific knowledge about the chemistry of soil fertility that the farmer, in his efforts to produce better crops, can and does rely very largely upon the chemist.

By contrast with all this let us turn to any of the more practical agricultural writers, from Fitzherbert to David Low, and see what they have to say about tillage. In their books we shall find discussions on the principles of tillage, and collections of practical hints, that are but little different from those that we may read in a modern text-book. Nowadays, indeed, we use tractors where our ancestors used oxen or horses. We have case-hardened and mild steels instead of the oak and iron with which they had to make shift. Our sheds are full of a variety of machines—mowers and sweeps, binders and threshing-plant—that they did not know. But we have no important implement of tillage that embodies any new principle. If we could walk our farms with our own great-grandfathers we should expect our binders, combine harvesters, and tractors to excite their wonder. But our ancestors would recognize our ploughs and harrows, cultivators and rollers, as no more than developments and variants of the tools they were accustomed to use. Moreover, we should have to admit that these developments have been made by practical men through the old procedure of trial and error, and not by physicists working upon modern scientific principles; we should have to admit that, in essence, the art of tillage is still the same as that which they tried to learn

—the art of making frost and thaw, drought and rain, do most of the work; and we should have to allow that whenever Nature proves unkind, or whenever we fail to cooperate with her, we are still constrained, as they were, to mash and mangle the soil into some very imperfect substitute for a real tilth.

I gather that the modern soil physicist can explain, in terms of sols and gels, why a soil should puddle if we cultivate it when the moisture-content is above a certain limit; why such puddled soil should dry into intractable clods; why these clods, when they have been frozen and thawed, or desiccated and rewetted, should become friable again; why the ease or difficulty of producing an 'onion-bed' tilth should depend so much upon the humus-content of the soil. It must be highly satisfying to the scientifically minded that such various facts should thus be made to fit neatly into their places in the general scheme of the universe. Moreover, the farmer is gratified to be told that he has been so very right in believing what he has always believed. But if he be a clay-land farmer, toiling to get some kind of a tilth in a dry spring following a wet winter, the profoundest knowledge of the physical chemistry of the colloids will avail him little.

In the early days of steam on the land there was a strong belief that the proper application of power would somehow revolutionize the whole process of tillage and enable the farmer to attain his object with infinitely less worry and sweat. Old Wren Hoskyns was the leader of this Band of Hope.

'Is it not astonishing,' he says,[1] 'that since the first introduction of Steam-power to the notice and assistance of mankind, nobody has ever attempted to apply it, *in its own way*, to the definite and simple work of cultivation? It is put to cut chaff, to make saw-dust, to granulate powder . . . and all by wheels—*circular motion* . . . but nobody can persuade his mind that by the self-same action, and no other, it can cut up a seam of soil, eight inches deep and five feet wide, and leave it behind granulated to as coarse or fine a texture as the nature of the seed or season may require, and inverted in its

[1] *Talpa, or the Chronicles of a Clay Farm*, chap. xxii.

bed. It is not ploughing, it is not digging, it is not harrowing, raking, hoeing, rolling, scarifying, clod-crushing, scuffling, grubbing, ridging, casting, gathering, that we want: all these are the time-honoured, time-bothered means to a certain RESULT. That result is a seed-bed: and a seed-bed is, simply described, a layer of soil from six to twelve inches in depth, rendered fine by comminution and as far as possible inverted in the process.'

Alas, poor ghost! Had you struggled (as I have done with very partial success) to understand the mysteries of sols and gels, you would have seen that the affair was not as simple as that. Your many disciples have spent much time and money in the invention of machines of the kind that you dreamt of—tilling machines. These upon occasion are by no means useless; but they cannot, like your Little Mole, 'cut a seed-bed out of the solid'. And so we still plough and harrow, hoe, scarify, clod-crush, scuffle, and all the rest, just as you were so unwillingly obliged to do; indeed, we may, if we choose, disk-harrow and rototill as well. We still, as you did, measure the degree of our achievement with the toes and the soles of our hobnailed boots, and thus decide whether to roll or scuffle, clod-crush or grub again—or whether to set the drills to work and pray that nature will forgive us the imperfections of our work. It is not that science has been idle, or has been wanting in sympathy with our difficulties. We still live in hope of some important new discovery. Already we are being told that we are too much afraid of scamping, and are inclined to till too much. The latest ingenious suggestion is that we might perhaps dispense altogether with this troublesome medium that we have struggled with through the ages and, instead, grow our plants in a colloid-free mixture of wire-netting and water. But meantime we carry on very much in the old way.

I suppose the moral of all this is just that the body of scientific knowledge underlying our farming is still far from complete, and that, wherever it lacks, we must still fall back upon the experience of our fathers. And since, even if scientific knowledge should increase in geometrical progression, it will be long before it is complete, much of

our practice must long follow rule of thumb. But there is another sense in which farming is an art—an affair of personal skill—and must remain that rather than become a science.

The day-to-day management of a farm involves the making of frequent decisions between one possible course and another. These decisions must often be made quickly and on incomplete knowledge; almost always there must be a balancing of possible advantage against risk, and generally there must be a measure of compromise. It often happens that two or more quite different tasks become urgent at the same time. The farmer sees that his clover is ready to mow and realizes that the quality of his hay will be the worse for every day that he postpones the cutting; but he also sees that his beet is in the fourth leaf, and knows that every day's delay in singling will mean a loss of sugar, greater or less according to the course of the weather. The look of the morning sky, and the previous night's weather forecast, may be more or less propitious for hay-making and may point to more or less rapid growth of the beet plant, with greater or less damage from overcrowding. More or less competent casual labour may be obtainable with more or less difficulty, and at greater or less expense. There may be a third urgent task in sight for the following week, or again there may be the probability of a lull in farm operations which will allow arrears of work to be overtaken. Any plan that the farmer makes must be capable of modification with a change in the weather. An exact mathematical calculation and balancing of all the probabilities is out of the question. The farmer must 'chance his arm'. The good farmer must sometimes come to a decision which will be wrong in the event. But one farmer is too often right, and another too often wrong, to permit the supposition that judgement is unimportant.

Each such problem that faces the farmer may be likened to that of a bridge-player when the first card has been played and the dummy hand exposed. The player has set himself a certain task. He will suffer a penalty if he should

fail to carry it through, and will gain some additional profit if he takes more tricks than he has bid. He knows his own resources, but can only guess at the forces pitted against him. He must generally take risks, but in each case he must count the chances and the consequences of success or failure. If a finesse fails, or if an improbable distribution of the opponents' cards should introduce some unexpected change in the problem, the original plan must be abandoned and a new one improvised. A bad player, who takes unjustified risks, must sometimes win where the good player would lose; but the balance of gain or loss, at the end of a hundred rubbers, will usually be a fair measure of the player's skill.

To scheme a single week's operations on a farm may call for a great deal of skill, judgement, and resource. But these qualities become more important still when we consider the whole task of management, which includes, besides this short-term planning, the devising of a long-term policy.

Take, for example, the management of a block of grassland. For this we have a large basis of scientific knowledge. We know the nutrient requirements of the desirable species of plants and we have lime, basic slag, potash salts, and nitrogen fertilizers. We know the differential responses of many plants to mechanical treatment, and we have harrows, disks, rejuvenators, rollers, rotary cultivators, and even grass squeegees. We know that certain plant associations—like that of ryegrass and white clover—will give us high production, and that, within quite wide variations of soil and climatic conditions, it is possible to produce and to maintain such associations.

But the maintenance of the ideal plant association may be cheap and easy (as on Romney Marsh) or difficult and costly (as on a Scottish mountain-side). Our object, in a given case, must be to improve only so far as improvement will, in the long run, be profitable. To set a limit to profitable expenditure would be difficult even if we could predict prices, and, since improvement must generally be slow and price-fluctuations may be sudden and large,

our calculations must be based upon assumptions and likelihoods.

We must remember, too, that the improvement of grass may set us new problems. With the greater density of stock our lambs may suffer from stomach worm and our calves get the husk. Our improved swards will bear less treading. Our rich grass may be 'too strong' for our young beasts.

Again, we know that the maintenance of the right balance between the desirable species, as well as the exclusion of inferior plants and weeds, depends upon the skilful adjustment of the number of mouths to the growth of herbage. If, then, the maintenance of a perfect sward were the ultimate object, and we could use our animals always as instruments of improvement, our task would be easy. To some extent, and upon occasion, we must use our animals in this way—otherwise we shall be killing our goose. But time and again we must balance the needs of the animal against the interest of the plant, and consider how far to mortgage the future for our immediate necessity.

A major choice, and one that has recently been much argued, is that between the permanent pasture and the ley. If we elect for the first, we must study to prevent the deterioration of the sward, and must be prepared to sacrifice, at times, the immediate good of the animal. If we choose the second, we accept the probability of deterioration, and are prepared to remake the pasture when necessary.

It is thus impossible to lay down any set of rules, based on scientific knowledge, for the management of grassland in general. A Leicestershire grazier may be shocked at what he considers the inefficient management of a North Country ley; if the north-countryman casts envious eyes upon a Leicestershire sward he is probably thinking that it would be a profitable venture to plough it up and grow potatoes on its stored fertility.

There is no doubt that success in farming depends partly on the breadth and depth of the farmer's know-

ledge; but it depends also, and depends more, upon his capacity to apply this knowledge to practical problems, giving due weight to each of the considerations that ought to govern his decisions. Economists who have carried out farm surveys, or have applied scientific analysis to farmers' accounts, have made such a remark so often that it has become a truism.

It is clear also, I believe, that skill and resource in management cannot be acquired except in actual practice. The most brilliant medical student cannot become a sound practitioner until he has served an apprenticeship. A competent mathematician can grasp the main principles of bridge in an hour, but he will not play well until he has played a good deal. We cannot hope that our agricultural colleges and universities will turn out ready-made farmers.

On the other hand, it is obvious that practice does not always make perfect, even where practice is superimposed upon a sound foundation of ability and knowledge. There are brilliant mathematicians who, even with practice, become no more than moderate bridge-players, and there are clever and industrious students who do not make capable doctors or farmers. Conversely, some of the people who succeed in all of these activities would certainly score no very high marks in a psychologist's intelligence test.

I believe we get a little nearer to the root of the matter if we say that success in such practical affairs depends upon our capacity to extract the lesson from the experience. Moreover, I do not believe that this capacity is purely a natural gift. I believe it can be developed like any other; and, speaking as a teacher, I am beginning to believe that, in our attempts to train farmers, we have not given enough thought to the means by which this may be done.

In practical affairs we must never assume that we have failed because we have been foolish, or succeeded because we have been wise. But neither must we assume that all our past actions have been governed by a uniform degree of unwisdom, and that the outcome has always been a

matter of chance. Both in medicine and in bridge, consultations post mortem serve a valuable purpose; and even if these are prevented by the recovery of the patient or the impatience of the partner, the doctor may usefully ponder his case-book, and the bridge-player may usefully reconstruct and reconsider the hand. So also must the farmer try to analyse both his successes and his failures. He must reconstruct the original problem, and reconsider the original plan. He must recall, step by step, every detail of his procedure. If he has failed in any degree, he must ask himself whether he has been blind to some risk or, seeing the risk, has failed to estimate its likely consequences; if he has succeeded beyond his expectations he must ask himself whether he has been merely fortunate, or somehow wiser than he knew; and all through he must strive to be fair, and no more than fair, to himself. Only by some such process can he hope to become better equipped to deal with the parallel problem another time.

I cannot end without touching on one other point. A painter may measure his success, in one sense, by the prices at which he is able to sell his pictures. This kind of success is not unimportant, for the artist must live. The farmer, too, may measure his success or failure by his profit-and-loss account, and here success is more important, for on it depends not only his own livelihood but that of his men. But most painters and most farmers strive for something more. The painter starts with a stretch of canvas and the farmer with a stretch of earth. Each sets himself the task of expressing, in his particular medium, some idea conceived in his own mind, that he thinks worthy; he gives all his energy and all his craftsmanship to the task, in the conviction that the work is worth doing for its own sake; and his reward will be large or small according as the achievement falls by only a little, or by much, below the aim.

That this kind of satisfaction is to be got from the land is obvious from the number of people who farm for pleasure—often with disastrous effects on their bank balances. In farming, however, the pursuit of artistry

alone is to be deprecated. The whole affair loses its point when the profit motive is absent; farming cannot be good if it be inefficient. The fullest satisfaction is to be had only when farming is the farmer's hobby as well as his business. If it be only the one or the other it can hardly be worth doing, for there are many more lucrative businesses, and many less expensive hobbies.

THE FARMER'S BUSINESS

By C. S. ORWIN

A FORMER Minister of Agriculture, happily still with us, once said to me: 'Farming, though perhaps the slowest, is certainly the surest way of losing money.'

Nevertheless, it is the farmer's business to make money. Not at any cost, of course; not by drawing out the fertility in his land without replacing it; not by the neglect of the permanent equipment of the farm; not by using it as the dumping-ground for a dealer's commission business. Farming that pays is good farming only if it be productive while maintaining the land in good heart and its equipment in good repair.

The twentieth century has witnessed changes in the farmer's business more rapid and more extensive, probably, than in any previous generation. The old three-course rotation, which is still in practice to-day, was general over nearly all the plough lands of England two hundred years ago, and it stretches back from that time to a period without date. For a thousand years, probably, and for far longer, possibly, the farmer's business had pursued a well-trodden path. The stimulus was self-supply rather than farming for profit. There was a common stock of knowledge, applied to a common system of farming under common control.

A combination of circumstances, the introduction of new crops, of new processes of husbandry, and above all the growth of opportunity for commercial farming, led ultimately to the evolution of agriculture from the traditional system to something more productive, to systems which produced increasing surpluses for the growing non-agricultural class. The break-up of the ancient practice proceeded variously in different places, both as to time and as to the form of that which replaced it. The universality of the simple three-field system had no counterpart in that which came after it. On the contrary, the greater range of crops, the improvements in the breeds

of the live stock, the variety of tillage implements, all combined to make possible a variety of shades and differences in farming practice adapted to local conditions, whilst leaving unaffected, of course, the fundamental principle that any rotation of crops must keep the land clean and in good heart. The hundred years prior to the repeal of the Corn Laws witnessed the dissipation of the age-old course of husbandry into many newly cut channels.

These, however, became as firmly established, most of them, in their own districts, as the simpler system had been in its greater range. Thus, when the great depression overtook the farming industry about 1880, continuing as it did for the next twenty-five years, the changes which it imposed upon farming practice took the form of reductions in corn-growing and in the ploughland area rather than of alterations in systems of ploughland farming.

The early years of the twentieth century saw British farming re-establishing itself, economically, as the price-level rose. It was now predominantly a live-stock industry rather than a corn-producing one, but in spite of all the range of artificial fertilizers which science had made available, the underlying theory of husbandry was still the inter-dependence of crops and stock. By universal consent, some three-quarters of the ploughlands must be applied to the production of corn and fodder for consumption by cattle and sheep, so as to have manurial residues in quantity to return to the land for the production of corn and potatoes for man. So recently as 1913, a Professor of Agriculture, experimenting for the first time with cost accounts, justified the heavy loss incurred in fattening bullocks on his farm on the grounds that it was the measure of the cost of the dung produced, this being an ingredient essential in the production of wheat. Up to 1914, farming rotations were stereotyped and sacrosanct—the four-course on the lighter lands, the five-course with an extra corn crop on the stronger lands, and all the variations from these which local circumstances had made possible. Up to 1914, the sheepfold and the dung-cart

were inseparable from the practice of the crop rotation, and manual labour was still the cheapest machine. When wages were from 2*s.* to 2*s.* 6*d.* a day, which is not necessarily so much as 12*s.* to 15*s.* a week, there was little inducement to economize in its use, to spend capital on labour-saving machinery, or to reconsider systems of farming in the light of their labour cost.

The four years of war and the regulation of agricultural wages and hours of work resulting from them were responsible for a revolution in farm practice. There is a pronounced time-lag in everything concerned with the land, and wages, which had been slow to respond to a rising price-level, were equally slow to follow it when it began its downhill course. Everything in the organization of production from the land and the distribution of its products called urgently for review.

Reconstruction was not to be easy. Agriculture was still a traditional art, it was a mixture of self-supply and commercial production, it was a way of life as well as a business. Hardly any of the controls applied in other industries were to be found in farming after the War, nor are they yet. The evolution of the industry has stopped short at a point not half-way between peasant production and scientific management. In the textile trade, for example, the cottage industry was absorbed in the local water-power mills, and these, in their turn, were superseded by the great factories made possible by the introduction of steam. At the same time, organization for large-scale production has been associated with organization for distribution, and federations of manufacturers, particularly of some commodities, control both production and price over almost all the world. In farming there is nothing comparable to this. On the production side, though agriculture in this country has left the peasant stage, it is still a one-man industry. The capitalist, the business manager, the technical adviser, the salesman, all wear the same hat. There is no specialization of the function of management, nor, except on the larger farms, of labour. It follows that there is no place in farming for mere brains.

There are no salaried managers, competing with each other for the best positions and striving to make two blades of grass grow where one grew before. Agriculture is an industry closed to every one whose ability is not supported by resources in capital.

Thus it has been inevitable, perhaps, that the tests and controls which guide the factory manager in the development of his enterprise are lacking, most of them, as aids to farm management. True, there has been a considerable development of milk recording, for the improvement of dairy herds and to facilitate the scientific control of feeding. But it is not too much to say that, throughout the whole of the farming industry, the practice of scientific book-keeping, as the only means by which to confirm or to correct the policy and the practice of the farmer, is so rare as to be virtually non-existent.

From these various limitations, it follows that there is a pronounced tendency towards the continuity of traditional practice. There is no opportunity for the brilliant young manager to break in upon it with innovations to increase production or to reduce its cost. In the rare cases in which exceptional ability is combined with financial resources, resulting in some profitable and revolutionary break with tradition, the organization provides no opportunity for training management, and it generally falls to pieces on the death of its founder, who has achieved a personal success without producing any effect upon general farming practice.

Thus, in the seventies of last century, George Baylis began the practice of a farming system in Berkshire, differing in its fundamentals from any in the country, which was to make him a great fortune at a time when the farming industry was at its lowest ebb, but which, so far from establishing a new school of practice, was to find hardly a single imitator. In the years of the great agricultural depression and the twenty years which followed it, he assembled an estate of twelve thousand acres and amassed a fortune of a quarter of a million pounds, by a system of arable farming without live stock, based on the intelligent

application of the results of Rothamsted research and defying the teaching and the practice of farmers of all time. An even greater business, covering some twenty-five thousand acres and valued for probate at more than four hundred thousand pounds, was built up by Samuel William Farmer in the adjoining county of Wiltshire about the same time, only to be dispersed after his death into its component units. A Lincolnshire labourer, William Dennis, another contemporary, exploiting the fen soils for the potato crop, founded a farming enterprise which after his death was floated as a limited company on the crest of the post-War boom for several million pounds, and it carries on miserably to-day with most of its assets realized and a debit balance which is never likely to be wiped out.

Wherever the great innovators have left or seem likely to leave some permanent marks on farming practice, it has been on account of some new device or machine. Thus there was Jethro Tull and his horse-hoeing husbandry, and, to jump nearly 250 years, the district in which he practised it has given us, to-day, Mr. A. J. Hosier, with his travelling milking bails and poultry arks, with which he has revolutionized dairy farming and egg-production on many farms. In these cases and in others like them, the new practice was associated with something tangible and visible, some appliance the efficiency of which was obvious and led to its widespread adoption. A new theory of the maintenance of soil fertility, such as that which George Baylis evolved, evokes nothing but the criticism of less original minds, while the large-scale organization, such as those built up by the genius of Samuel William Farmer and of William Dennis, is doomed to break up again in the absence of any openings in farming for the professional managing director.

If, then, it must be accepted that there is something inherent in the cultivation of the land which makes it a one-man affair, can anything be done to bring it under scientific control, or must it remain in all its essentials an art and a way of life rather than a business?

The country might have been content with an agricultural industry such as this during the long years in which farming was regarded merely as one of its many activities, pursued by classes of people who liked it or who contrived to make it profitable in a competitive market. Farmers themselves, however, were finding, more and more, that the ideal of farming as an art and as a way of life could not be maintained in the face of the spread of industrial organization. The standards of living of organized labour in other industries made the idea of a return to an English peasantry, working long hours for small rewards, a complete anachronism, and the steady tendency of agricultural wages to approximate to industrial wages, which culminated in the setting up of the Agricultural Wages Board in 1917, imposed upon farmers the need for another conception of their work.

These were the conditions in which the Development Commissioners were led to provide finance for investigations into the economics of agriculture, by the constitution of the Agricultural Economics Research Institute, at Oxford, in 1913. The Institute and the various centres of study ancillary to it exist to supply to the small-scale units of agriculture information about the business of production and sale which large-scale industrial units provide for themselves.

The study of the business of farming falls into two main categories. First, it can furnish fundamental information which should be essential to the State for the formulation of its agricultural policy. Second, it can supply information to the farmer about the organization of his business and its economic results, which is essential to him if he is to exercise anything better than a rule-of-thumb control.

Let us consider, first, how economic research can assist in the formulation of national policy. In practice, of course, this policy is determined, often, more by political expediency than by economics, but it is important, none the less, that the facts should be ascertained and made known. For fifty years and more, for example, it has been

accepted by politicians of all parties that the closer settlement of the land was desirable, either for the appeasement of the landless labourer, or to reward the demobilized soldier, or to combat urban unemployment. Acts of Parliament have been passed to provide smallholdings, large sums have been spent under them and an extensive administrative machine has been constructed. Here are the results of a simple investigation undertaken in the very early days of the Institute to show the relative economy of agricultural holdings of different sizes.

If maximum employment were the only consideration, there is no doubt of the superiority of the smaller farms. In the following Table, the farms comprised in surveys of three different districts were grouped by size and the manual labour in each group was calculated per 100 acres of land.

Influence of Size of Farm on Efficiency of Manual Labour

Size group	*Arable land per 100 acres*	*Persons employed per 100 acres*
Acres	Acres	No.
District 1		
Under 50	25·0	7·1
50–100	26·0	5·0
100–50	21·0	4·0
Over 150	19·0	2·4
District 2		
Under 50	17·0	7·1
50–100	22·0	6·4
100–50	21·0	4·2
150–250	11·7	3·3
Over 250	18·0	2·6
District 3		
Under 100	36·7	4·1
100–300	45·8	3·0
300–500	53·1	2·3
500–700	50·3	2·5
700–1000	60·4	2·3

It will be seen that in each district the demand for labour fell as the size of the holdings rose. It might be argued,

however, that the higher labour requirements on the smaller farms are the measure of their greater productivity. But here is the result of another survey which shows that, although there is more intensive use of the land on the smaller farms, the value of each man's work is directly proportionate to the size of the farming unit.

Influence of Size of Farm on Production per Acre and Production per Person Employed

Size group	*Sales per acre*	*Sales per person*
Acres	£ s. d.	£ s. d.
Under 50	11 19 9	168 19 0
50–100	9 19 2	156 2 0
100–50	7 19 1	189 0 0
150–250	7 5 8	222 12 0
Over 250	8 4 4	316 19 0

The unit cost of equipping farms with live and dead stock is also related to their size. Here are figures of the cost of implement equipment per 100 acres on farms of different sizes disclosed by surveys in three districts.

Influence of Size of Farm on Value of Implement Equipment per 100 acres

District 1		*District 2*		*District 3*	
Size group	*Value*	*Size group*	*Value*	*Size group*	*Value*
Acres	£	Acres	£	Acres	£
Under 100	446	Under 100	374	0–49	328
101–300	286	101–80	266	50–99	294
301–500	192	181–300	212	100–49	269
501–700	164	Over 300	157	150–99	234
701–1,000	173			200–99	213
				300–499	179
				Over 500	139

The capital invested in implements and machinery is not directly productive, and it is clear that the capital cost bears more heavily on the smaller farms.

The evidence is that, while closer settlement may increase the volume of employment and the total quantity

of production, the cost of equipment of small farms may be more than that of larger ones and the standard of living which they afford to the workers engaged is relatively low. As Dr. Doreen Warriner has pointed out in her study of European peasant countries, the tendency to move out of agriculture is a symptom of an economically progressive society; it is not merely a transfer from one occupation to another, but a process of development from a lower to a higher level of labour-productivity. Thus a national land policy which is designed to promote closer settlement must be justified by political rather than by economic considerations.

The study of the economics of sugar-beet cultivation is another example. Under the stimulus of a subsidy on home-grown sugar, first provided by the Government in 1925, a new industry was to be supported through its infant years by Treasury help on a scale diminishing over ten years, at the end of which it was expected to stand alone. A study of production costs throughout this period showed that the industry could never be self-supporting in open competition, and that the home production of sugar added to the difficulties of the cane-sugar industry of British colonies. The ultimate decision of the Government to maintain it, notwithstanding, was taken presumably once more on grounds of expediency rather than of economics.

More recently, the opportunities for the economist to supply information which should be essential in the guidance of State action to assist the farmer's business have been enormously increased. The policy of agricultural protection which has been developed in the last few years, found the country devoid of any experience from which to calculate the effects of measures for the regulation of food-supplies and prices. In the field of price-fixing, nothing is more difficult than to determine the cost of production. It may be easy to calculate, with reasonable accuracy, the cost of wheat-growing, say, on a particular farm or even in a particular district. For the country as a whole, however, nothing more can be done than to fix

some price, by the process of trial and error, at which farmers are prepared to produce the quantity of the commodity required. An interesting example of this process in operation was furnished by the Wheat Act, 1932. Under its provisions, a deficiency payment to produce a return of 45*s*. a quarter to the farmer was guaranteed, this figure being entirely arbitrary, but the quantity of wheat to which it should apply was limited. If, therefore, the figure were too low, this quantity would never be forthcoming, as only the exceptionally efficient amongst farmers, or those on exceptional soils, could afford to produce at this level. If, on the other hand, it were too high, production would exceed the limit, and the effective price would fall in proportion, roughly, to the excess. The latter, in fact, is what happened, for the guarantee of 45*s*. stimulated production to the point at which the effective price fell to about 39*s*. 9*d*. a quarter. The inference is, of course, that a guarantee of about 40*s*. would have sufficed to produce the supplies specified in the Act, but once more political expediency rather than economics was the determining factor, and instead of lowering the guarantee, the State preferred to make it effective by raising the limit on the quantity to which it should apply.

Other farm products, besides wheat, are now subsidized, but an instrument in the execution of national agricultural policy even more important, perhaps, than the subsidy is the regulation of competing imports by tariffs or by quotas. If the problem of price-fixing be complicated, that of import-regulation is even more difficult. It is too generally assumed that goods arriving on the British market in the course of international trade are dumped goods, but while the control of dumping might be expedient, any interference with normal trade might have serious reactions upon the economic life of the country. Again, the influences on the price-level of changes in the volume of home production are often overlooked, and any fall in prices is apt to be attributed to the weight of imports. Examples are provided by recent experience of the markets for lamb and for eggs.

The heavy decline in the price of home-grown lamb, last year, was due less to the competition of imported lamb than to increased production at home. Egg-producers, too, often are loud in their demands for further control of the import trade by tariffs or quotas, but a study of supplies and prices made at the Agricultural Economics Research Institute, in 1937, demonstrated that it is the amount of the home production which is the largest factor in price-changes. Between 1925 and 1935, variations in the home output were responsible for 66 per cent. of the annual and for 88 per cent. of the seasonal price-changes.[1]

But State interference in agriculture need not end with subsidizing home production and restricting competing imports. There is the great problem of distribution to be faced, the study of which is an important branch of agricultural economic research. The spread between wholesale and retail prices was investigated by a Departmental Committee in 1923, but administrative action on its recommendations is still deferred. High distribution costs may be caused by a redundancy of distributors, a redundancy of services, or, as is sometimes alleged, by agreements among distributors to maintain big margins.

In 1925, a beginning was made, at Oxford, with the study of distribution by an examination of the methods of sale of live stock. Live-stock marketing is found to be governed by certain characteristics necessarily associated with live-stock production. First, the standardization of cattle, sheep, and pigs is impossible and renders sale by sample or description difficult. The fact that the prospective buyer must see the whole of the live stock in question and as many more lots as possible for purposes of comparison, greatly increases the number of agents, the cost of transport, and the permanent equipment required for their sale. Secondly, the marketing of live stock is bound up with established market-places, over which the local authorities consisting of tradesmen, never of farmers, have full control under ancient charters. The result is that these markets,

[1] O. J. Beilby.

designed for an age when each local district was self-supporting, are utterly unsuited to modern conditions, when the whole country is knit together by railways, when there are great concentrations of industrial workers, and when half of the nation's meat is imported. Thirdly, very many of the existing anomalies are due to the financial dependence of the farmer upon the middleman, and the remedy must be sought farther back in devising a solution of the whole difficult problem of agricultural credit. These are chief, perhaps, among a considerable number of governing conditions that are found to emerge in a study of live-stock marketing. The outstanding conclusion of the investigation was that fat stock should never enter the market on the hoof, but that centralized slaughter should be organized—associated, of course, with the maximum utilization of by-products and the sale of meat to butchers by grade and description. A re-organization such as this could hardly be effected without State assistance, and although the work which led to these conclusions attracted no attention, it is interesting to note that it anticipated all the more important of the findings of the Reorganization Commission for Fat Stock set up under the Agricultural Marketing Act in 1932.[1] The rate of progress in the application of the remedies recommended is so slow as to suggest once more that the political power of vested interests is stronger than economic argument. However, the facts are now established, and it is for the farming interest to fight its corner.

More recently, a beginning has been made with the examination of the costs of milk distribution. The value of milk as a protective food for all sections of the population has been increasingly appreciated in recent years, but the main obstacle to an all-round increase in milk consumption is its high price to the consumer, much of which is due to distribution. A preliminary study of town delivery costs, made at the Agricultural Economics Research Institute in 1937, illustrates at once the need for reductions in distribution costs and the difficulties to be

[1] F. J. Prewett.

expected in securing them. There is the waste incurred through the redundancy of distributors, and some restriction of their numbers would doubtless be advantageous. But even if competition were reduced in any district to three or four firms, the proportion of houses served by each would be very much below the maximum, and delivery costs could be reduced to the lowest level only if a single retailer were left to serve every one within the area. This, however, would deprive the consumer of his right to choose between milkmen. Some idea of the potential economies may be gained from the results of the Oxford investigation, by comparing the average delivery costs of certain areas with those to be anticipated if a milk-round density of 100 per cent. were possible, that is, if a single retailer were to distribute all the milk required.

In the first town, where delivery was undertaken by hand-barrows, the weekly delivery costs per household fell by 13 per cent. in congested areas as the round-density rose from 35 per cent. to 55 per cent.; on housing estates they declined by 6·2 per cent. as the round-density increased from 50 per cent. to 65 per cent. In the second town, where two persons were employed on each round operating a horse van, the weekly delivery costs per household declined by 5·4 per cent. in congested areas as the round-density rose from 50 per cent. to 65 per cent.; on housing estates they fell by 5·6 per cent. as the round-density rose from 45 per cent. to 65 per cent. And in the fourth town the weekly delivery costs per household declined by 9·3 per cent. in all areas as the round-density increased from 40 per cent. to 60 per cent.

Another source of waste is the provision of more than one daily delivery. Not all the customers want it, but the roundsman has to make a full journey to reach those who do, and in one town it was observed that a demand for a second delivery by only 6 per cent. of the households served by one firm increased the average delivery costs by 0·2*d.* per gallon. So long as the Milk Marketing Board's practice of fixing minimum retail prices remains, competitive conditions prevent distributors from reducing the

number of services offered to their customers without incurring grave risk of loss of custom. The exclusion of competition in prices has intensified competition in services.[1]

The problem of the reduction of distribution costs is indeed gigantic. Not all distributors are inefficient, nor are the services they offer necessarily redundant. But while the Co-operative Societies prefer to adopt a policy of dividends rather than one of cut prices, while municipal trading is prohibited by statute, and while, as has just been said, the tendency of orderly marketing, so called, under the newly organized producer-control may be to stabilize distributors' margins at levels called for by the least efficient, little progress will be made in the economics of distribution until statutory powers are given to the Food Council to investigate the books of wholesale and retail distributors of food products.

Let us turn now to consider how economic research can assist the individual farmer to exercise some sort of scientific control over the management of his business. Farming for self-supply in a primitive community may be a matter mainly of maximum production: labour, manures, anything which is applied to increase the physical output of the land is well applied. But farming for the market in a modern industrial state is measured by a different standard: capital and labour are well applied only if the costs which they represent are more than recovered in the prices of the resultant products. This is the test of any farming system and of every farm manager.

As Sir Daniel Hall himself has said, farm management has its own fundamental science, namely, book-keeping. The men of genius—Baylis, with his corn-growing rotation; Hosier, with his downland farming; the Bomfords, with their mechanical ingenuity; Abbott, with his group of specialized industries organized to fit into the framework of one farm—these men and their like may have hit upon things which transcend all else in the influence

[1] J. S. Cripps.

which they exert upon the success of the business. But for the majority of men success is dependent, Martha-like, on being careful about many things, and the financial analysis of the system which accountancy and records make possible is the means to the exercise of that care. The turnover of the average farm is too little to justify an office equipment and clerical assistance. On large or on intensively farmed holdings this may be called for, and the determination of labour and product costs may repay the effort they require. Otherwise, a yearly inventory and a record of receipts and payments are what can be expected of every farmer, supplemented by as many other records—time-sheets for his men; records of food-consumption by live stock; records of the application of fertilizers, &c.—as he can be induced to keep. He is then equipped with the means for making a complete statistical and financial examination of his farm management.

Dealing, first, with fundamental facts, what is the distribution of his capital amongst the different branches of his business? What is the proportion of it invested in those directly productive, such as live stock, tillages, &c., and in those only indirectly productive, such as implements and machinery, tenants' fixtures, &c.? What is the rate of his turnover and how does it vary in the different departments of the farm? How is his gross annual expenditure apportioned between rent, labour, feeding-stuffs, manures, implements and machinery, and tradesmen's bills? In what proportions do the different farm departments contribute to his gross annual income? What does his expenditure and his income under the various heads amount to per acre of the land he occupies? What is his total profit and his profit per acre, and what rate of interest does this represent on the capital invested?

The only demand which the record and account keeping needed for these purposes makes is upon the farmer's time. He need not be an accountant to undertake this work, and he will find a wide choice of account books designed to simplify it for him. A small proportion of farmers are already doing it, while others pay professional

firms to do it for them. But the value of the work lies not in doing it but in the uses to which it is put, and it is in the interpretation of his figures that the farmer may need assistance. It is here that the economic advisory service can help. It is not the business of the advisory economists to keep farmers' records for them, but with the information that they have about the economics of the different farming systems of their localities they can contrast the performance of the individual with that of the group and can point out the directions in which his practice and his results diverge from it. Here, for example, is the analysis of a farmer's income and expenditure arranged to show him the ways in which it differed from the averages of a group of farmers similarly engaged and in the same locality.

This chart consists, in effect, of a series of clinical thermometers, which measure the reactions of the individual compared with the rest of the group. Take, for example, column No. 1, 'Size of Farm'. The largest in the group was 205 acres, and the smallest 103 acres, while the average of them all was 166. A scale is constructed, of an equal number of readings above and below the average, on which is marked the place occupied by the farm under consideration. Farm No. 4, the example we have taken, is 177 acres, that is to say a little above the average size, and its place is marked on the scale by a black line between the figures 176 and 181. So for the rest of the chart, the position of this farm in each of the other measurements of farm activity is marked in the same way.

Certain things emerge. Taking the last column first, this farm has the highest margin between direct expenses and cash receipts (col. 16). This is not because its total income per acre is exceptional (col. 8), or that it depends more than other farms upon dairying (cols. 3, 6, and 7), or that its rent is exceptionally low (col. 13). What strikes the eye is that the average milk yield per cow is the highest of any (col. 4); that the milk realized the highest price (col. 5); that very little was spent on purchased foods, while nearly all the home-grown grain was fed to the cows (cols. 9 and 10); that a large part of the labour was

Chart I. *Showing how* Farm No. 4 *varied from the average of Twenty-one other milk-selling farms*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
									Foods		*Labour*					
	Size of farm	*% arable*	*No. of milk cows*	*Average yield per cow*	*Average price per gallon*	*Income per acre from milk*	*Income from milk as % of total income*	*Total Income per acre*	*Cost of bought foods per acre*	*Grain fed as % of total grain grown*	*Wages paid per acre*	*Value of family labour per acre*	*Rent per acre*	*Misc. bills per acre*	*Total out-goings per acre*	*Margin between direct expenses and cash receipts per acre*
	Acres	%	No.	Galls.	s. d.	s.	%	£ s.	s.	%	s.	s.	s.	s.	£ s.	s.
Highest .	205	88	36	—768—	—1 3—	133	78	12 8	63	100	52	47	42	25	12 6	—109—
	200	80	34	734	..	127	75	11 15	58	96	49	43	41	24	11 13	98
	195	73	33	700	..	120	72	11 2	54	92	46	40	40	23	11 1	86
	190	66	31	666	..	113	69	10 9	49	88	43	36	38	21	10 8	75
	186	59	30	632	.	106	66	9 17	44	—84—	41	32	37	20	9 16	64
	181	52	28	599	..	99	64	9 4	40	79	38	29	—36—	19	9 3	52
	176	44	27	565	..	93	61	8 11	35	75	35	25	35	18	8 11	41
	171	37	25	531	..	86	58	7 18	31	71	32	22	33	16	7 18	29
Average .	166	30	24	497	1 2	79	55	7 5	26	67	29	18	32	15	7 6	18
	158	26	22	474	..	72	53	6 15	23	63	27	16	31	14	6 17	13
	150	22	21	451	..	66	50	6 6	20	58	24	14	29	13	6 9	8
	142	19	19	428	..	59	47	5 16	17	54	22	12	28	12	6 0	3
	134	15	18	404	1 1	53	45	5 7	14	50	20	10	27	11	5 12	− 2
	126	11	16	381	..	46	42	4 17	11	46	—17—	8	25	9	5 3	− 7
	119	7	15	358	..	39	40	4 8	9	42	15	7	24	8	4 15	− 12
	111	4	13	335	..	33	37	3 18	6	37	13	5	23	7	4 6	− 17
Lowest .	103	0	12	312	1 0	26	34	3 9	3	30	11	3	22	—6—	3 18	− 22
Farm 4 .	*177*	*18·6*	*20*	*768*	*1 3*	*94*	*50·4*	*9 6*	*5*	*84*	*17*	*31*	*36*	*6*	*5 7*	*109*

family labour and cash wages were low (cols. 11 and 12); and that miscellaneous tradesmen's bills were the lowest of any of the farms in the group.

Here, obviously, is a hard-working family farmer who has graded up his dairy herd to a high pitch and is getting the top price for his milk. He is growing crops for cow-feed rather than for the market, with apparently excellent financial results, and he is looking twice at every sixpence before he buys anything. It would be difficult to offer any advice to this man on how to increase his efficiency. It is possible that some of the financial success is the result of undue economy on the general maintenance of the farm or its equipment, reflected in the small expenditure shown in cols. 14 and 15, and that this will involve a day of reckoning sooner or later, but an inspection of the farm would settle this point.

Chart II shows the position of another farm, No. 74, in the same group of dairy holdings. Looking at its cash margin, it appears at once that it is on the wrong side, the farm being one of the worst in the group (col. 16). In size it is roughly the same as farm No. 4 analysed above (col. 1); the income from milk is about the same (col. 6); the rent is very similar (col. 13); milk sales are even a larger part of the total income (col. 7); the total income per acre is fully up to the average of the group (col. 8). We must look elsewhere for the explanation of the bad financial results.

In the first place, this farm has the largest number of cows, but one of the lowest average milk yields (cols. 3 and 4). The farmer depends more upon bought than upon home-grown concentrates (cols. 9 and 10), while his labour is almost entirely hired (cols. 11 and 12). Further, his miscellaneous tradesmen's bills, though not much above the average, are a great deal higher than on farm No. 4.

The analysis suggests clearly enough that here is a farm on which, although milk-selling is the most important branch, the dairy herd calls for drastic improvement. The cost of concentrated food is well above the average of the group, while the milk yield per cow is one of the

CHART II. *Showing how* FARM NO. 74 *varied from the average of Twenty-one other milk-selling farms*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
									Foods		*Labour*					
	Size of farm	*% arable*	*No. of milk cows*	*Average yield per cow*	*Average price per gallon*	*Income per acre from milk*	*Income from milk as % of total income*	*Total income per acre*	*Cost of bought foods per acre*	*Grain fed as % of total grain grown*	*Wages paid per acre*	*Value of family labour per acre*	*Rent per acre*	*Misc. bills per acre*	*Total out-goings per acre*	*Margin between direct expenses and cash receipts per acre*
	Acres	%	No.	Galls.	s. d.	s.	%	£ s.	s.	%	s.	s.	s.	s.	£ s.	s.
Highest .	205	88	—36—	768	1 3	133	78	12 8	63	100	52	47	42	25	12 6	109
	200	80	34	734	..	127	75	11 15	58	96	—49—	43	41	24	11 13	98
	195	73	33	700	..	120	72	11 2	54	92	46	40	40	23	11 1	86
	—190—	66	31	666	..	113	69	10 9	49	88	43	36	38	21	10 8	75
	186	59	30	632	.	106	66	9 17	—44—	84	41	32	37	20	9 16	64
	181	52	28	599	..	99	64	9 4	40	79	38	29	36	19	9 3	52
	176	44	27	565	..	93	61	8 11	35	75	35	25	35	18	8 11	41
	171	37	25	531	..	86	58	7 18	31	71	32	22	33	—16—	7 18	29
Average .	166	30	24	497	—1 2—	79	55	7 5	26	67	29	18	32	15	7 6	18
	158	26	22	474	..	72	53	6 15	23	63	27	16	31	14	6 17	13
	150	22	21	451	..	66	50	6 6	20	58	24	—14—	29	13	6 9	8
	142	19	19	428	..	59	47	5 16	17	54	22	12	28	12	6 0	3
	134	15	18	—404—	1 1	53	45	5 7	14	50	20	10	27	11	5 12	−2
	126	11	16	381	..	46	42	4 17	11	46	17	8	25	9	5 3	−7
	119	7	15	358	..	39	40	4 8	9	42	15	7	24	8	4 15	−12
	111	4	13	335	..	33	37	3 18	6	37	13	5	23	7	4 6	−17
Lowest .	103	0	12	312	1 0	26	34	3 9	3	30	11	3	22	6	3 18	−22
Farm 74 .	*190*	*56·3*	*36*	*404*	*1 2*	*92*	*63·0*	*7 6*	*44*	*53*	*49*	*14*	*34*	*16*	*8 13*	*−11*

lowest. The place of the farm on the chart in other particulars does not seem to call for comment, and unless the poor herd performance can be explained by an outbreak of contagious abortion or some other disaster, the farmer would be well advised to attempt to improve the average performance of his cows and perhaps to reconsider the construction of his food rations.

Financial analyses of individual farm management can be made in the same way for any other type of farming, and by collaboration between farmers and agricultural economists an advisory service of real value could be built up by this means.[1]

This is the kind of help which the farmer may expect to get from simple financial accounts in tightening up the efficiency of his management. It must not be supposed that divergencies from the averages of other producers in his class point necessarily to weaknesses in his own organization. They should arrest his attention, however, and he should satisfy himself, for example, that, if his feeding-stuffs are costing him more, it is because his milk records are better, or that, if his labour bill is higher, it is because his total farm sales are also above the average. In the absence of any such satisfactory explanations, he has a definite pointer to something in his management which he should reconsider.

But more than this can be done to stimulate efficiency, if the records available have been compiled in greater detail. There are rare instances of farmers who supplement their financial records with cost accounts, while throughout the country as a whole, the advisory economics service is engaged in making cost-of-production surveys, either of products or of farming systems. With the aid of such cost-of-production studies the process of tracking down and stopping leakages can be carried a stage farther, for while a financial analysis may suggest that total labour costs, for example, are too high, a cost analysis may show

[1] This method was devised by Professor H. C. M. Case, of Illinois; the examples are from a farm management survey made in South Oxfordshire by R. N. Dixey.

where this loss of effective work is being incurred. Here is an analysis of the costs of harvesting by Combine-Harvester on fifteen farms, tabulated in descending order of efficiency as indicated by the total cost per quarter:[1]

Costs of Harvesting by Combine-Harvester

	Proportion of Total Cost			*Cost per acre*	*Yield per acre*	*Cost per quarter*
Farm Number	*Combining* %	*Trucking* %	*Drying and Dressing* %	£ *s. d.*	*Bushels*	*s. d.*
14	50	24	26	12 3	36	2 8
4	57	12	31	14 8	37	3 2
12	65	12	33	13 10	33	3 4
6	72	8	20	17 5	41	3 5
5	67	11	32	13 11	32	3 6
1	50	11	39	14 11	33	3 7
2	59	8	33	12 8	26	3 10
Average	57	13	30	16 3	30	4 5
13	66	6	28	12 8	23	4 6
3	53	16	31	1 0 0	32	5 0
10	63	10	27	17 4	27	5 2
9	45	21	33	13 3	20	5 3
15	55	17	28	1 1 9	32	6 1
7	55	10	35	1 0 9	25	6 8
8	57	13	30	1 0 3	23	6 11
11	53	10	37	1 2 11	24	7 2

It will be observed that about 57 per cent. of the total costs are incurred on cutting and threshing, about 30 per cent. on drying and dressing, and about 13 per cent. on trucking. Farm No. 6 stands about midway in the top half of the table, when assessed by the standard of total cost per quarter, but an examination of the analysis suggests that it may owe this place to its high crop yield per acre, the highest, in fact, of all the farms, rather than to any special efficiency in handling the harvest. The acreage costs are the highest of any farm in this half of the Table, as also is the proportion of total cost represented by cutting and threshing. Thus, the question for the farm manager here is: Are these costs due to the exceptionally heavy crop which he had to handle, or to anything which can be improved in his manner of handling it?

Or take Farm No. 9, about the middle of the lower half

[1] A. Bridges.

of the table. Here the acreage cost is almost the lowest of any, but so also is the yield, and the analysis of the total cost shows that trucking accounted for a higher proportion of the whole than on any of the farms except No. 14. Here the questions for the manager to consider are: Can he do anything to increase the yield of his crop without incurring diminishing returns, and is there any reason—abnormal distances from the fields to the drier, for example—to account for the high cost of trucking?

Sometimes simpler decisions on more fundamental questions have to be taken by the farmer, in which the evidence of costs can help. What, for example, is likely to be his experience if he should replace some of his horse teams by a farm tractor? While it may be a fair assumption that he will not regret it if his farm be big enough, it is more satisfactory to have the confirmation of figures.

Here are the costs of maintaining a stable of six working horses for one year, on a medium-sized, light-land farm:[1]

Cost of Working Horses, Gloucestershire

	£	s.	d.	£	s.	d.
Foodstuffs:						
Oats	69	1	1			
Meadow hay	14	11	8			
	83	12	9			
Grazing	17	6	3			
				100	19	0
Labour: Manual				43	13	7
Shoeing				16	10	0
Depreciation and repairs to harness				5	7	0
Depreciation on horses				8	7	2
Veterinary, medicine, &c.					13	3
				£175	10	0

Number of horses	6
Total number of hours worked	11,805
Number of hours worked per horse	1,967
Cost per horse-hour worked	*3·56d.*

The cost of a pair of horses was approximately 7*d.* per hour worked. Now consider the following cost of operating

[1] S. J. Upfold.

a 10–20 International tractor. The figures cover a five-year period of work.[1]

Working Cost of Tractor, Hampshire

	£ s. d.	£ s. d.
Fuel:		
Paraffin	132 5 10	
Petrol	7 10 7	
Oil and Grease	60 15 7	
		200 12 0
Repairs and Miscellaneous Expenses		78 6 11
Depreciation		154 13 9
		£433 12 8
Total number of hours worked		3,480
Cost per tractor-hour worked		2·5s.

Here then is the issue. Will a man with a tractor do more than four times as much work as the man with a pair of horses? And if this be doubtful, will the imponderable advantages of the tractor—the speed at which it works, its adaptability for threshing and other stationary work—make it, nevertheless, an economical substitute?

Again, what is the answer of the landlord to the tenant who wishes him to improve his cowsheds and dairy equipment so that he may qualify for the premiums on certified milk? Here are the average costs of producing Grade A (T.T.) milk on about twenty farms:[2]

Summary of Costs of Producing Grade A (T.T.) Milk

	Number of farms included in average	*Average cost per cow*	*Average cost per gallon of milk*
		£ s. d.	d.
Food and grazing	12	24 9 8	9·58
Direct manual labour	18	9 7 1	3·66
Sundry expenses:			
Dairy	21	1 2 5	0·44
Veterinary	22	18 6	0·36
Water-supply	15	14 10	0·29
Depreciation on equipment	19	3 6	0·07
Repairs, &c.	20	2 2	0·04
Depreciation on cows	19	3 9 4	1·36
Total costs		40 7 6	15·80

[1] A. J. Marval. [2] V. Liversage.

Here, next, are the average capital costs incurred on a group of thirty-five farms in adapting buildings and providing additional equipment for the production of certified milk:[1]

	Cost per cow		
	£	*s.*	*d.*
Adapting existing cowsheds, or building new ones . .	5	16	0
Adapting existing dairies, or building new ones . .	1	4	3
Additional equipment and plant (for milk in bulk only) .	2	11	0
Total capital cost per cow	£9	11	3

Lastly, here are the costs of producing milk in an open-air milking-bail with a herd of 60 cows, having an average yield of no more than 460 gallons:[2]

	Per cow			*Per gallon*
	£	*s.*	*d.*	*d.*
Food-stuffs:				
Concentrates	6	3	6	3·2
Hay and straw	3	0	0	1·6
Grazing	1	17	6	0·9
Total	£11	1	0	5·7
Labour	3	6	11	1·8
Bail expenses (running, upkeep, and depreciation)	1	7	6	0·7
Total costs	£15	15	5	8·2

The difficulty of maintaining a tubercle-free herd is said to be much less under the open-air system than under the cowshed system, and the relative cheapness of the milking-bail, whether moving over the fields or fixed in the farm-yard, may well appear to furnish the landlord with the answer to his tenant's request. At the same time, the relative cheapness of milk-production by the bail suggests that, until every acre of grassland which is fitted for open-air dairying is thus equipped and used, the last

[1] R. N. Dixey.
[2] R. N. Dixey and M. Messer.

word has not been said upon the question of how to give the public cheaper milk.

In England, to-day, we have arrived at a system of land tenure which is virtually dual ownership. In spite of the break-up of many of the big estates which has characterized the agricultural history of the last twenty years, two-thirds of the cultivated area of the country is still farmed on the landlord-and-tenant system. There was a time when the landlord played a more leading part in the use of the land and in the control of farming, the time when, as Lord Ernle wrote, 'the Duke of Bedford at Woburn, Lord Rockingham at Wentworth, Lord Egremont at Petworth, Coke at Holkham, and numerous other landlords, headed the reforming movement'; when 'Fox, even in the Louvre, was lost in consideration whether the weather was favourable to his turnips at St. Anne's Hill'; when 'Burke experimented in carrots as a field crop on his farm at Beaconsfield'; when 'Lord Althorp's first question to John Grey of Dilston, who called on him during a serious crisis of affairs when he was Chancellor of the Exchequer, was: "Have you been at Wiseton on your way up? Have you seen the cows?"' In those days the landlord's lease to his tenant prescribed the crops which might be grown, the order of cropping and the method of disposal, all of these covenants being dictated by what was established as the best practice according to the knowledge that then prevailed. It imposed heavy penalties for breaches of covenants. But as the nineteenth century proceeded, and progress in farm practice developed with unprecedented rapidity, the demand for something more flexible than the control of the long lease and its covenants increased. On top of this, in the last quarter of the century came the great agricultural depression, which deprived the landlord of much of his interest in agriculture and of the means to indulge it. As a consequence, first, of the Golden Age of agriculture which demanded more liberal treatment for the improving tenant, and, second, of the agricultural depression following it

which crippled the landed gentry, a new chapter in the history of land tenure was opened. The Agricultural Holdings Act, passed in 1875, was the first statute to intervene in the contractual relations of landlord and tenant, and it was the precursor of many, each one transferring the control of the land more and more from the landlord to his tenant. Freedom to carry out improvements and compensation for their cost on quitting the farm; freedom of cropping; security of tenure; the right to kill ground game; the abolition of penal rents—these things have followed one after another, while in more recent years commodity marketing boards, producer-controlled, have been created, and the Cabinet has welcomed a Minister of Agriculture chosen from the ranks of the past Presidents of the National Farmers' Union. The last sixty years, and in particular the years of the present century, have witnessed the rise of the farmer into a position of responsibility for the use of the land which is almost absolute, and it is his duty to develop the efficiency of his farming by every means available to him.

SOIL SCIENCE IN ENGLAND 1894–1938

By SIR E. JOHN RUSSELL

IN 1894, when A. D. Hall started work at the South-Eastern Agricultural College, at Wye, it could hardly be said that soil science existed in England. There were chapters on soil in that useful classic, Warington's *Chemistry of the Farm*, and every lecturer on agricultural chemistry included soil in his course along with fertilizers, feeding-stuffs, animal nutrition, dairy chemistry, insecticides, and a variety of other subjects. In the United States the study of soil was more advanced. King, at Wisconsin, and Whitney, at Washington, had begun their pioneering measurements of the physical properties of the soil in relation to soil fertility, continuing and extending the earlier work of Wollny, in Germany; but no systematic account appeared in English till King's book came out in 1895. The American investigations were admirably summarized by R. Warington in his 'Lectures on some of the Physical Properties of Soil', in 1900, which was a great advance on anything that had been done before. But Warington had to complain that there was no English work on the subject: all his material had to be drawn from overseas. The complaint was fully justified, in spite of fifty-seven years of agricultural experiments at Rothamsted: curiously enough neither Lawes nor Gilbert seemed particularly interested in the soil.

Hall's book, *The Soil*, appeared in 1902 and it was the first account applicable to English conditions. It became indispensable to all who had to advise farmers, and who wished their advice to have something more substantial than a purely empirical basis, and it was, of course, the daily handbook of those few who were studying the soil in the hope of learning something more about it. Several American and Continental books appeared about the same time, and we may put the period 1880–90 as one in which many new investigations were started, while from

1900 onwards books on soil were written in increasing numbers.

PLANT FOOD IN THE SOIL

1. *Soil analysis*

Most of our work on the soil in those days was concerned with the study of the plant food contained therein. This, indeed, went back to the foundation of agricultural chemistry: it had led, at the beginning, to the long-continued controversy between Lawes and Gilbert on the one side, and Liebig on the other, the one really serious controversy in our subject till we come to those that have happened in our own times.

Lawes' and Gilbert's experiments at Rothamsted, on which our knowledge was based, showed how small the yields could ultimately become if the crops depended solely on the soil, and also how large they might be if properly fertilized. Some of the older followers of Lawes and Gilbert, with more zeal than discretion, had urged that the whole secret of crop production was the proper use of artificial fertilizers, and when I first started going among farmers I found to my astonishment that I was expected to act as advocate for artificial fertilizers as against farm-yard manure. But we refused to take up this line: in point of fact the issue was already dead before 1900. Hall was too good a gardener to reject the help that farm-yard manure could give to the cultivator of the soil.

The practical problem presented to us in 1901 was, as now, to advise farmers what were the most suitable crops for their soils and what manurial treatment should be given. So a good deal of soil analysis was done. We estimated nitrogen, loss on ignition, calcium carbonate if any, potash and phosphate by Dyer's method and sometimes by hydrochloric acid extraction. There was, of course, no pH in those days, and no way of estimating acidity: actually it was rare for us to find an acid soil, as our good farmers understood the need for lime. But in those days, as now, the analyst's report on his figures, if

it was to be of any use, had to be tempered with a good deal of experience on the particular type of soil and in the particular region: no analytical method gave entirely trustworthy results. If was easy, of course, to pick out soils highly deficient in some particular constituent such as phosphate, potassium, or lime, but usually farmers knew about any marked deficiency of that sort. The Americans had shown the great importance of mechanical analysis, and we usually did this as well. In spite of a great amount of work in the intervening years soil analysis still remains a difficulty. It has been rendered more precise in certain continental countries, Sweden, Germany, &c., where large numbers of farmers have united to form circles for carrying out a uniform scheme of field experiments on a certain crop, and an analyst has examined every individual soil. With this background of local knowledge, the analyst can give fairly accurate advice about the manuring of that crop on similar soil types in that region. This method is not practicable in England. At Rothamsted we make a far smaller number of field experiments, but of a good design, so that the results can be statistically examined and their relations to chemical and other data properly worked out.

2. *Soil surveys*

Partly with the view of systematizing advisory and field experimental work, but chiefly for the purpose of giving a fuller description of the region, Hall started a soil survey of Kent and Surrey and afterwards of Sussex. I joined him later, and we found, as Topley had done before us, that the geological basis was for this region quite satisfactory. Luxmore had already made a beginning with a survey near Reading. Later surveys were made by J. Hendrick and by G. W. Robinson, and here the geological basis was not quite so suitable: of course there was no reason why it should be, because the geological classification depended primarily on age and the soil classification had to take account of composition. Soil surveys still continue to be done, but in this country they have become part of the

advisory organization, so that each area adopts its own procedure and the question of classification hardly arises. Much useful work has been done by G. W. Robinson, W. G. Ogg, W. Morley Davies, S. G. Brade-Birks, and others, but we have as yet nothing corresponding with the soil maps and the centralized surveys of the continental countries or of the United States.

3. *Plant food and soil exhaustion*

Considerable excitement and controversy was caused for a time when Milton Whitney, the chief of the United States Soil Bureau as it was then, declared that the plant-food content of the soil was relatively unimportant because it always sufficed for full crops, and that the undeniable benefits of fertilizers were due not to the supply of more food, but to the throwing out of action of some harmful factor. The water-relationships of the soil he regarded as far more important. Hall soon showed the fallacy of the main argument, but, like other controversies that have to be taken seriously, this one served the useful purpose of emphasizing the need for a wider view of soil fertility, and it kept us from confining ourselves too exclusively to the stores of plant food in the soil.

The old idea that soil exhaustion was brought about simply by the using up of its plant nutrients by continued plant growth is now known to be incomplete. It is true that soil productiveness can almost always be enhanced by adding more nutrients in the form of suitable fertilizers, but the extent to which it can be reduced by withholding fertilizers is easily exaggerated. Probably no plot in the world has been so starved as the unmanured plot on Broadbalk wheat field, which has had no manure since 1839 and has been cropped with wheat every year since 1843, and yet the yields have not fallen indefinitely. It is true that for a number of years they ranged about 12 bushels per acre, which is low, of course, but weeds were largely responsible and an almost insuperable difficulty. In recent years, more success has been attained in keeping the land clean, and the yields have been much higher: in

1934, the various sections of the plot averaged 21·2 bushels per acre, and in 1938, 24·6 bushels per acre: one section that had been fallowed in 1937 gave no less than 39 bushels per acre: 22·5 cwt. of grain and 25·6 cwt. of straw; while the other three, that had not had this advantage, gave respectively 18·6, 19·7, and 21·3 bushels of grain (11·0, 11·7, and 12·4 cwt.) and 12·5, 12·9, and 13·1 cwt. of straw per acre—which for its centenary without manure was not bad. One of the Hoos field barley plots has been without manure since 1852, and this, in 1938, gave 19·7 bushels or 10·1 cwt. of grain and 8·2 cwt. of straw per acre, while two others, practically as long unmanured, having received in their early days only certain ashes devoid of plant food and nothing now for a long period, gave respectively 23·5 and 25·9 bushels or 12·2 and 13·0 cwt. of grain, and 10·3 and 10·8 cwt. of straw. The similarity with the wheat yields is interesting, but even more is the reflection that it is going to be a very long and tedious business waiting for these yields to come down to nothing through sheer exhaustion of the plant nutrients. These yields are impressive when we reflect that many wheat and barley growing countries of the world have less as their average. But in terms of dry matter in the total produce—grain, leaves, stems—they work out only at about 1 ton per acre. Mangolds and potatoes grown on continuously unmanured plots at Rothamsted yield about the same weight of total produce though the figures look much more meagre: about 3 tons of potatoes and 4 tons of mangolds. It appears that our Rothamsted soil can almost continuously yield about 1 ton of total dry matter per acre, provided it is properly cultivated, but that if suitable fertilizers are added the yields go up to an extent determined by the crop. They may rise to ten or even twenty times this value for mangolds, to four or five times this value for potatoes, to three or four times this value for wheat.

Until recent years chemists took account only of the nitrogen, phosphate and potash, and lime in the soil, but it is now known that other deficiencies may occur. The

possibility was foreshadowed by Mazé, at the Institut Pasteur, Paris, and its physiological significance was studied by Gabriel Bertrand, but the first element to be studied in any detail was boron, which was shown by Dr. Katherine Warington, at Rothamsted, in 1923, to be essential to plant growth. Only minute quantities were needed, but in their absence plants became diseased or refused to grow. Subsequently the symptoms of boron deficiency were recognized in a number of crops: sugar-beet in Great Britain, swedes in Scotland, apples in New Zealand, possibly certain vegetables also; the remedy is simply to add some 20 lb. borax per acre. Deficiencies of sulphur, manganese, copper, zinc are now recognized, and indeed at the present time when anything goes wrong the first thing sought is some new lacking element. For the moment agricultural chemists are deficiency-minded, and the well-equipped soil laboratory has now to be provided with a high-class spectrographic equipment.

FIELD EXPERIMENTS AND THE METHODS OF UTILIZATION OF DATA

All these questions concerning plant food in the soil, however, turn in the end on the results of field experiments and the methods of working up the data. One of the chief changes that has taken place in recent times has been the introduction of statistical methods of examination. Lawes and Gilbert founded the tradition of amassing large quantities of field data. Daily meteorological observations were made, and various records from the experimental plots: great care was taken to ensure the accuracy of the figures. The Agricultural Colleges and experimental farms followed the tradition, and if all the data have been kept they must by now amount to a colossal pile. But it cannot be said that much information has been extracted from the figures. Lawes and Gilbert themselves never used more than a fraction of the data carefully collected, entered in triplicate, and stored away. When Hall came to Rothamsted he studied the voluminous memoirs and extracted from them the material for his

Book of the Rothamsted Experiments, but there still remained much unused data. When I became Director in 1912 and saw the vast stores of figures to which we were daily adding, I felt that some definite attack on them must be made: if they were useful we ought to extract the information they contained, otherwise there was no point in continuing to accumulate them. Gilbert had the remarkable gift of seeing a huge table of figures as if it were a picture: he could pick out the salient points and, very shrewdly, even on inadequate data, draw conclusions frequently justified by fuller investigations. Hall used five- or ten-year averages and examined seasonal effects by comparing typical wet with typical dry years, or, as Gilbert had done, by comparing the best seasons with the worst. I did not suppose that I should get out anything new with these methods and decided on an entirely fresh approach. I knew that population experts had designed special mathematical methods for working up the vast masses of figures yielded by a Census, and I decided to find some one who could apply these to our figures. Fortunately I got in touch with R. A. Fisher, who after an examination of the Broadbalk data satisfied himself and me that they were susceptible to mathematical treatment, and he and his colleagues and successors are continuously studying sections of our accumulated data to extract all the information they can yield. Important studies have been made of the deterioration of yield under the various manurial treatments, and of the effect of fertilizer treatment on the reaction of the growing plant to changes in weather conditions. Neither of these groups of problems could have been studied by the older methods.

Fisher soon showed that neither the field data nor the meteorological data were as good as they might be. There was considerable uncertainty about the field data because it was impossible to say how much of the difference between one plot and another was due to the treatment and how much to soil and other irregularities. Erratic results were sometimes obtained which naturally tended to foster the attitude of mind: 'You never can tell.' The

meteorological data suffer from the drawback that the measurements at present taken do not faithfully define the meteorological factors of importance for plant growth. This latter problem is still unsolved, though we are hoping that some better measurements may still be devised. But the improvement of the field data was definitely a first call on our activities: we could not let the challenge pass. Fisher saw that the only way to obtain data capable of being properly evaluated was to replicate and randomize the treatments: further, that greater accuracy would be attained by combining several different inquiries in one large complex experiment than by having a number of separate tests. These principles have been systematically developed by F. Yates and his colleagues, and in consequence field experiments can now be designed to study even complex questions and to give data of known validity. The designs are complex, and each experiment may involve anything from 27 to over 200 plots, but the data are presented along with the standard errors, and so any relation that may be sought between them and any other set of data can be worked out. The new methods have proved so much more useful than the old that they are now used almost all over the Empire and in parts of the United States. From Rothamsted we are advising on, or in some cases actually conducting, experiments on rubber in Malaya, tea in India, cotton in the Sudan, and oil palm in West Africa, while our old research workers are using the methods for experiments on sugar-cane and rice in India, tea in Ceylon, to say nothing of numerous experiments in the United Kingdom. The methods are spreading, and constantly being improved.

Still further improvement in the field experiments has been effected by extending the range of the observations. In the old experiments final weights only were taken. Now a number of growth measurements are taken, selected by the plant physiologist, D. J. Watson, as having some relation to the physiological processes in the plant. The relations between these measurements and the final yield are worked out in association with the Statistical

Department. For the plant, as for us, the child is father to the man, and the final yield is the resultant of many events that have gone before, some being much more important than others. The advantages of being able to make a reasoned forecast of probable yield are very considerable, and there is hope that this may yet be possible. A beginning has been made with wheat, and it has been shown that certain easily measured properties make it possible in early summer to form a fair estimate of yield. But something much better will come.

THE ORGANIC MATTER IN SOIL: FARM-YARD MANURE, NATURAL AND ARTIFICIAL

I have already referred to the mid-nineteenth-century controversy—now forgotten though its echoes still persisted in 1910—about the relative merits of farm-yard manure and artificials. We fully recognized the advantages of farm-yard manure even though we could not then entirely explain them, nor for that matter can we do so now. But our chief purpose was to increase the quantity available, for the production was certainly falling off with the shrinkage in area of arable land, and the partial abandonment of winter feeding of cattle in the buildings. E. H. Richards and I studied the losses on making and storing of manure, and he and H. B. Hutchinson studied the conditions for the conversion of straw into the black humus material which forms the basis of the manure. This work was developed and became the Adco process for making compost, which has now spread so widely that probably some 100,000 tons are made annually: it also forms the basis of a well-known French method for making compost for mushroom culture, and of other methods of composting.

An alternative method of supplying organic matter has proved less generally useful. Green manuring failed badly in the Woburn experiments, though it answered at Rothamsted when a good green crop could be grown. Experiments at other centres gave some success and some failures, but

it is not possible to foretell which will happen. Work on the subject has now been restarted.

Much labour has been spent in trying to identify the chief organic substances in the soil. The work has not proved very fruitful, and but little work is now done on the subject. Schreiner and Shorey identified a vast number of substances in their extracts, and Sven Odén tried what physico-chemical methods could do. H. J. Page applied modern organic and physical methods to the problem and showed that humus formation was closely associated with the lignin in the plant residues, and Waksman boldly assumed that humus is undecomposed lignin plus dead fungous mycelium. New methods are needed before further progress can be made, and for the present the work is at a standstill.

THE MICRO-ORGANISMS IN THE SOIL

Since 1900 there has been a great change, both in methods of investigation and in general outlook, in regard to the micro-biology of the soil. By 1894, the main facts of the nitrogen cycle and its relation to soil micro-organisms were established. The brilliant investigations of Winogradsky had finally enabled him to isolate the nitrifying organisms, while those of Hellriegel and Wilfarth had cleared up the mystery of the fixation of nitrogen by leguminous plants. Percy Frankland, who not long before had been an assistant at the Royal Agricultural College, had written a most attractive little book *Our Secret Friends and Foes*, giving an account, far more vivid and enthralling than many a romance, of the widespread activities of bacteria in agriculture. So, in 1900, we began with the definite idea that bacteria played an extremely important part in the soil, particularly in the production of plant food, and that soil fertility might be estimated by some measure of bacteriological action. Various empirical methods were devised by Remy and by Löhnis in Germany and by Lipman in the United States, including ammonifying power, nitrifying power, nitrogen-fixing power, and I used the rate of oxygen absorption as a

comprehensive measure. But it was soon clear that these methods would not get us far in the study of soil fertility. A happy mistake on the part of my laboratory boy opened up the work on partial sterilization. As a lecture experiment, I had regularly shown that sterilization greatly reduced the rate of absorption of oxygen by soil. There came a day, however, when the boy burnt out the autoclave and so I had to use a rather ineffective steam sterilizer. To my astonishment this partial sterilization considerably increased the rate of oxidation. Hutchinson, working in the new James Mason Bacteriological Laboratory which Hall had persuaded Mr. J. F. Mason to build, joined me in following the matter up, and we showed that bacteria were not, as had been tacitly assumed, the only micro-organisms active in the soil: active protozoa were also present, and since then other groups—algae, actinomycetes, and various other fungi—have been investigated. The soil population is now known to be extremely complex and numerous. Winogradsky, Cholodny, Thornton, and others have designed improved methods for studying it *in situ*, and Thornton's counts have shown how enormously great the bacterial numbers are, and also that they fluctuate continuously. The subject is back again in the melting-pot, but we hope that in the new and greatly enlarged bacterial laboratories now being erected at Rothamsted it will be possible to reduce it to shape.

For the present the most fruitful investigations are those on the nodule organism by Fred, at Wisconsin, Bartel, in Sweden, and Thornton, at Rothamsted. The old problem of inoculation for leguminous crops, which some twenty-five years ago Bottomley had made into a kind of agricultural Philosophers' Stone, has been solved and has become a recognized part of ordinary farm practice wherever it is needed. Part of the difficulty arose from the fact, only slowly realized, that there are numerous groups and strains of the organism: not only are there organisms specific to certain groups of leguminous plants but within each of these there are strains varying greatly in their power of fixing nitrogen within the plant. A singularly ineffective

strain of the clover organism occurs in certain hill districts of Wales: it invades the roots and makes nodules, but these make little progress and contribute little or nothing to the nutrition of the plant. In these circumstances clover has but little chance of growth. A vigorous strain has now, however, been discovered that will not only dominate the native ineffective strain but, once within the clover plant, fixes nitrogen easily, and so leads to vigorous growth.

Perhaps the most interesting of these investigations are those of Thornton showing the relation of the organism to the plant. During the cotyledon stage of growth the rootlets are not attacked by the nodule organisms. But as soon as the true leaves appear the rootlets excrete some substance which causes rapid multiplication of the nodule organisms in the soil. These, in turn, excrete something which causes the root hairs to grow and to curl; at the bend the bacteria enter. They then push up into the root and start multiplying, building the nodule to house the colony. Some differentiation of the root tissues takes place forming a network of tubes linking up the nodule with the circulatory system of the plant; along this, sugar is brought to the nodule and the products of nitrogen fixation are taken to nourish the plant. This differentiation can take place only if a small quantity of boron is present; otherwise the colony remains disconnected from the circulatory system, the products of fixation are not removed and so fixation ceases; no sugar comes to feed the bacteria and so they attack the root. A relationship which is normally a beneficial symbiosis becomes, instead, a harmful parasitism.

These root and bacterial excretions suggest obvious parallels with the auxins now being studied by botanists, and the next stage is to bring in a biochemist to study them, and, if possible, to find out the stages of the nitrogen fixation itself. This we hope to do in the new buildings.

THE WATER-SUPPLY IN THE SOIL

Lawes and Gilbert never followed up their early work on the water requirements of plants, and the subject fell

into abeyance for many years until some of the Continental and especially the American investigators took it up again. It was through the American work that interest was revived in England, and Hall was the first seriously to take the matter up.

My first experiments with him were to study a conductivity method for estimating at frequent intervals the variations in moisture content of the soil *in situ*. The method failed, partly because of the difficulty of getting proper contact between the electrodes and the soil, partly because of complications caused by changes in concentration of the soil electrolytes, partly also because we did not know the route by which the current was passing between the electrodes. Various methods had been devised by the American workers for estimating some of the water relations of the soil, and we made determinations of moisture capacity and other supposed constants, which, however, were all quite empirical. The current view then was that water moved in the soil by capillarity, and the standard illustration in the lectures was to set up capillary tubes, and also two plates of glass to show the phenomena of capillarity; but the fact that the experiment usually broke down unless everything was spotlessly clean made us deeply suspicious that it was hardly applicable to grains of soil that were very far from clean. Later on B. A. Keen showed that the supposed constants had no real existence and that the simple capillary-tube theory did not apply. W. B. Haines showed that the geometry of the pore space enforced on the soil moisture important characteristics of distribution and movement previously unexplained. Recently R. K. Schofield has raised the investigation to a new level and put the water relations on a quantitative basis. The power with which a soil holds its moisture is regarded as a suction pressure; and Schofield has adopted methods for measuring it over its whole range from air-dry condition to saturation. The scale of measurement has to be logarithmic because of the great range of the figures. Thus, if a soil is so nearly dry as to be in equilibrium with an atmosphere of 50 per cent. relative

humidity, the moisture is held with an intensity expressed by a suction pressure of 1,000,000 cm., while if the soil is saturated with water so that the excess can start to drain away, the force of retention is only of the order of a column of 100 cm. This is a manageable column, but the other one is not: it is higher than Mount Everest. The logarithms of these numbers, however, are manageable, and the figures are expressed on a scale called by Schofield 'pF' on analogy with the pH scale, which in the same sort of way expresses the intensity of the acidity of the soil.

This scale is of special value in relation to questions of water-supply to the plant, and it may be expected to find useful application in irrigation problems.

THE WIDENING SCOPE OF SOIL RESEARCH

Prior to the War our acquaintance with overseas work and workers was confined mainly to the United States and to the Empire; we had really little contact with our Continental colleagues, but occasionally we received Continental visitors at Rothamsted. In the main the very long German papers of those days were put aside to be read later, though the French papers received more attention, perhaps because more people then read French than German. Many English agricultural experts, however, knew little or nothing about Continental work.

The War changed all this, and after it was over we began to develop the habit of conferring with our colleagues on the Continent. So we learned of the ideas that had been growing up there, particularly of a method of soil classification that had been started in Russia, based on the mode of formation of the whole block of soil from the surface down to the parent rock—a method so comprehensive that it could only have been worked out in a vast region which included a wide range of climatic conditions. Three great processes of soil formation were recognized. Where the soil water soaked downwards, as in many northern regions, the soluble substances were carried with it and usually interacted with some constituents of the lower

layers so that they became deposited there. A fairly regular series of changes was traced, and the process received its Russian name 'podzolization'. Where the soil water tended to move upwards, as in parts of the hot, dry countries, and especially where it contained salts in solution, another set of changes took place and the resulting soils were called 'solontchaks'. In between, where the water neither soaked far down nor came to the surface, and where there was a grassy vegetation devoid of forest, a soil of entirely different character arose called a 'chernozem'. There were, of course, shades and variations and much interplay between these various processes; but the basis remains comprehensive and logical. The classification thus set up was not of particular interest to us, as most of our soils fell into one great group: the feebly or moderately podzolized. But there was much more involved than classification: many ideas which, if not entirely new, were presented in a new setting, and their impact has led to a considerable widening of our outlook on soil problems. In particular they introduced us to the Continental work on clay, and to the necessity for investigating the well-known fact that a fertile soil easily takes on a granular structure, each grain of which is a complete microcosm of the whole soil: for it was made clear that the soil remains productive only so long as these grains persist; directly they are destroyed the soil loses its productiveness.

MODERN VIEWS ON CLAY

In 1900, our ideas on clay were virtually those of Way extended by the physical investigations of Wollny and the American workers. Hall and Morison, following up a striking paper by Joly, studied the flocculation phenomena and showed their great complexity, but the methods then available were inadequate to permit of great progress, and little was known except that clay was a complex silicate possessing remarkable physical properties and considerable power of interaction with solutions of metallic salts. Then X-ray analysis was developed and applied to the

complex silicates by W. L. Bragg and others, and in consequence hypotheses have been set up as to its constitution which can be further examined—and, as we all know, it is in this way that science progresses.

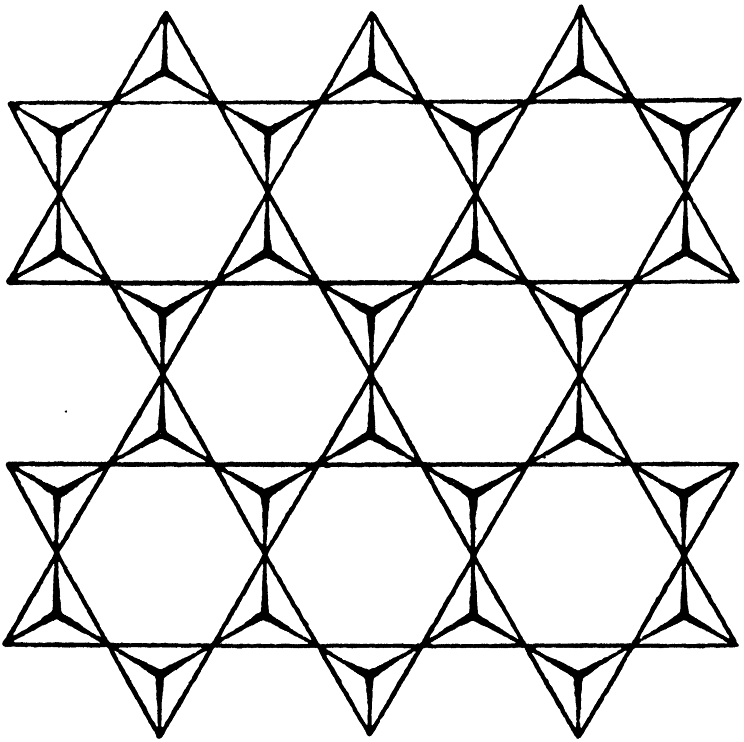

Fig. 1

In temperate regions the clay fraction appears to consist of kaolinite along with something called Mineral X. Without models it is not easy to describe the 'patterns' given by X-ray analysis, but they are illustrated in Fig. 1. The basis is of course the molecule of silica usually written SiO_2 for convenience, but this is not a true picture of its constitution, for it represents the molecule as a closed system incapable of joining up with any other, whereas we know that the silicon-oxygen combination has an

astonishing power of building up highly complex silicates. The truer picture is obtained by regarding the silicon atom as the centre of a tetrahedron, with four bonds reaching out to four atoms of oxygen which it shares with its neighbouring silicon atoms or with other elements. In one arrangement these tetrahedra are attached to each other at the corners of the base so as to form endless sheets of hexagonal rings: this forms the micas. In quartz and feldspars the groups are built up in a three-dimensional network. Kaolinite is built up of layers of silicon-oxygen tetrahedra, in a kind of hexagonal pattern (like the micas), alternating with layers of aluminium hydroxide in which each aluminium atom is surrounded by six hydroxyls in an octahedral arrangement. The connexion between the silica and alumina layers is made by the replacement of two of the six hydroxyls round each aluminium atom by two of the free oxygen atoms of the silicon-oxygen layer.

Montmorillite, another clay mineral, apparently contains these same layers, but they are arranged in sandwiches, each aluminium hydroxide layer coming in between two silicon-oxygen layers. Each sandwich is about 6·6 Ångstrom units[1] in thickness and successive sandwiches are separated by gaps which vary from about 3 to 14 Ångstrom units according as the clay is dry or wet: this separating of the sandwiches by the molecules of water as they squeeze in accounts for the swelling of the clay when it is wetted. The pattern is shown in Fig. 2. The clay mineral X of our temperate climate is at present regarded as a hydrated mica.

This whole subject is being further investigated at Rothamsted by Nagelschmidt, with much friendly help from the Royal Institution laboratories.

In this complex structure of silicon, aluminium, oxygen, and hydrogen atoms there are obvious possibilities of replacing some of the hydrogens by other cations, so bringing about the extensive base-exchange phenomena long known as among the most characteristic properties of clay.

In the clay fraction of a normal fertile soil the major

[1] 10,000,000 Ångstrom units (Å) = 1 mm.: 10,000 Å = 1 μ.

part of these replaceable cations are calcium. All our agricultural methods and implements, and all our varieties of agricultural crops, have been evolved to suit a calcium clay. But it sometimes happens that the calcium becomes replaced by another element and then our methods and varieties become unsuitable. A familiar example arises when a once fertile soil is flooded with sea water for a suffi-

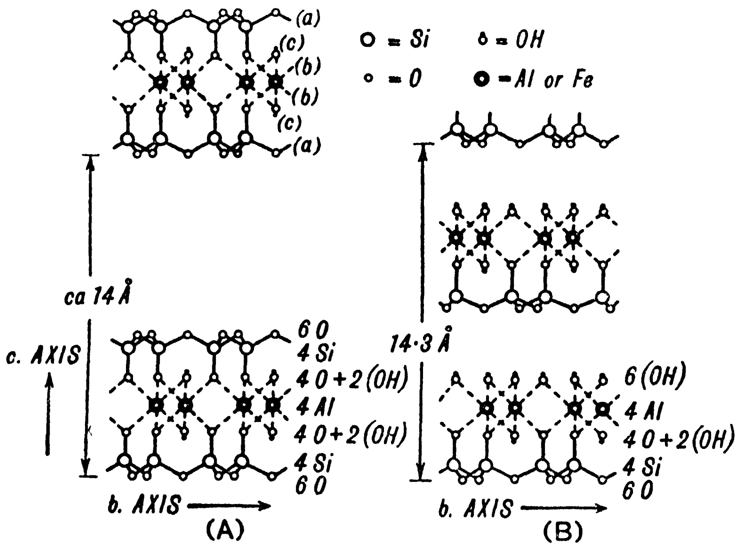

Fig. 2

ciently long time to damage it badly: the calcium becomes partly replaced by sodium and magnesium. This change has been several times independently discovered: by Paul de Mondésir in 1888, by Dymond in 1899, and by Gedroiz in 1912, but the papers were always overlooked till Gedroiz's were discovered, translated, and circulated by the United States Department of Agriculture in 1922 and they, and the earlier ones, have now passed into the literature. The subject has since been investigated in detail in Holland by Hissink, in connexion with the Zuyder Zee, and by Greene, in connexion with irrigation in the Sudan, and others. In Holland, the aim has been to make a fertile calcium clay out of the sodium clay

present in the old floor of the sea that has now become dry land and is to be cultivated.

The conversion is effected by adding calcium carbonate where necessary (it is not always), providing adequate drainage so that the sodium chloride or other salt can be washed out of the soil, and cultivating and cropping the soil so that carbonic acid can be produced, thus bringing the calcium into solution and enabling it to interact with the sodium in the clay.

Attempts have been made to find out how these exchangeable cations lie in respect to the general architecture of the clay particle. Are they on the outside, or in the spaces between successive sandwiches, or in the smaller spaces inside the structure of the tetrahedra? It seems clear that they are fairly accessible, for they can be replaced by large cations like methylene blue, that could not, so far as is known, wedge themselves in among the tetrahedra. The simplest view is that they mostly reside on the outside of the clay complex.

One of the most characteristic properties of the normal calcium clay is that it readily forms into grains or crumbs when it is first wetted and then dried. This property depends both on the exchangeable cations and on the wetting liquid. Crumbs are not formed if the cations are too large (e.g. the complex organic cations) nor if the molecules of the liquid are large or non-polar: thus a calcium clay dispersed in non-polar liquids like carbon tetrachloride or benzene, or with polar liquids having large molecules such as amyl alcohol, forms no crumbs on drying but falls to a fine powder. These observations have been made by E. W. Russell, who set up an ingenious hypothesis to account for them. When clay particles are suspended in water there is, as is generally agreed, some dissociation of the cations, so that the central part or micelle takes a negative charge to balance the positive charges of the dissociated cations. These charges cause some orientation of the polar molecules of the liquid round them, and this becomes more marked the greater the surface density of charge: the micelle causes the water

molecules to direct their negative end outwards, while the dissociated cations orientate them in the opposite direction. As the amount of moisture diminishes, a cation can attract polar molecules already orientated by two different clay particles, thus building up an orientated chain which restricts free movement of the various parts and so gives

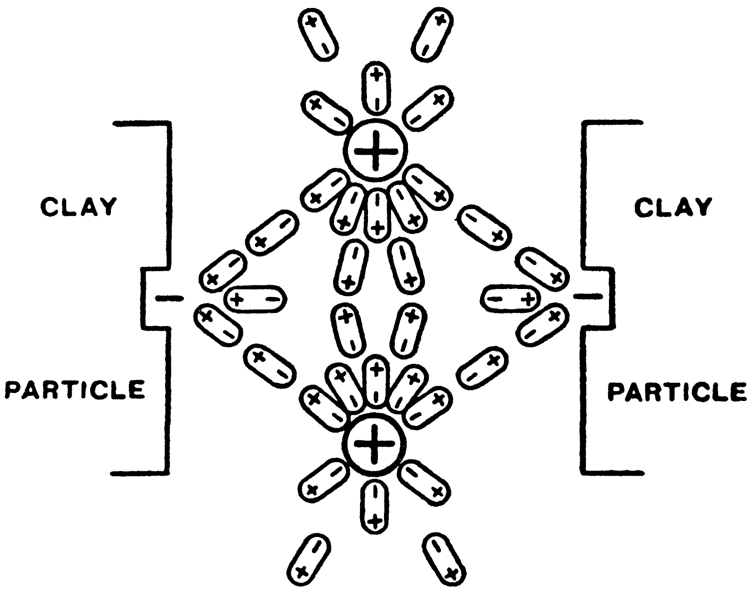

FIG. 3

a certain amount of rigidity: this increases as more water is lost. Fig. 3 shows a diagrammatic representation of the process.

The mechanical strength of the crumb depends on the number of cations associated with the micelle: i.e. on the base-exchange capacity. The higher the number of cations the greater the possible number of connecting links.

Crumbs differ in their stability towards water. Those formed in calcium or acid clays retain their individuality when wetted, while those formed from sodium clays do not, but fall down to a paste. The reason is not yet known.

These crumbs are not the same as the flocs formed

when an electrolyte is added to a dilute suspension of clay in water but there is some relationship between them. Crumbs formed from a flocculated paste are always stable: those from a deflocculated paste may be unstable, though they are not necessarily so.

Humus possesses a certain number of clay properties in spite of its wide difference in chemical composition: its micelles or ultimate particles are associated with cations; it can be dispersed in water and flocculated; it has base-exchange properties and the power of crumb formation; for equal weights it appears to be more potent than clay but the processes have not been so fully studied, there being as yet no means of doing for humus what modern optical and X-ray methods are doing for clay. The general facts are clear, however, and in consequence humus also has a marked power of causing crumb formation in soils.

These crumbs can be built up into aggregates or granules, which give the granular structure to a soil in good tilth. This process is not understood, but it can be effected by the growing plant and is part of the action of the growing root on the soil. These crumbs are seen at their best in virgin chernozem soils: a lump of soil can be easily crushed in the hand and falls down to granules about the size and shape of wheat seeds. Some of the old grass-land soils of England behave similarly. The Russian soil workers keep the word 'granular' for this most perfect development. In ordinary cultivated soils the granules are not so well developed: the lumps are not so easily crushed and they give a certain amount of powder or fine dust. The most imperfect structure is called cloddy: the better, though imperfect, we may call crumby. This is the usual structure of good English soils.

It is not known how plant roots bring about this remarkable aggregation: the simplest supposition is to associate it either with the carbonic acid excreted from the roots or with the changes in the ions resulting from the selective absorption by the plant root. But whatever the mechanism, plants vary in the extent to which they can build up soil structure: clover and grass seem to be specially potent.

SOIL FERTILITY: ITS CONSERVATION AND DESTRUCTION

We are now able to set out the picture of a fertile soil as at present understood. Its mineral part is made up chiefly of particles ranging from 1 mm. diameter downwards but mostly below 0·2 millimetres. It contains about 5 to 20 per cent. of clay sufficiently rich in associated cations, mostly calcium. It also contains humus, also rich in associated cations, in which, too, calcium predominates. Further it contains all the elements of plant nutrition. It has been long enough under grass or native vegetation to have acquired the proper crumb structure and, as all these constituents are present in every part of the soil, each crumb or granule is a perfect microcosm of the soil, as an eighteenth-century writer would have said. Under suitable climatic conditions, and with an adequate and properly distributed rainfall, a soil like this would be very productive.

How is the fertility of such a soil to be kept up? Forty years ago most chemists would have said: By maintaining the proper supply of plant nutrients, the amounts being determined by chemical analysis. Nowadays one would have to add to this: A close watch must be kept on the lime status of the soil because of the great importance of maintaining a high preponderance of calcium in the cations of the clay and of the humus. There should always be a reserve of calcium carbonate, not because this is particularly valuable in itself—indeed, as shown later, it may do some harm: but so long as it remains, the preponderance of calcium ions in the humus and the clay is assured.

Above all, the structure of the soil must be preserved and this is best done by growing periodical clover or mixed seeds leys for a longer or shorter period. Where this is impracticable the structure can be maintained by frequent dressings of farm-yard manure, as on some of the Rothamsted plots, but this is not feasible as a farm operation; in some circumstances green manuring is successful.

One of the most serious problems of modern times is the destruction of soil fertility, and even of the soil itself,

which has occurred in recent years and is still going on. It is not due to the exhaustion of plant food, as the nineteenth-century economists feared, following Crookes' remarkable address in 1896. A far more important cause of destruction of soil fertility is the loss of calcium ions from the clay and the humus. If these are removed by leaching, by physiologically acid fertilizers or manures, or in any other way, the properties of the residual clay and humus change. The first effect is that the reaction of the soil becomes acid, which is unfavourable to most cultivated crops, though in varying degrees: some, such as rye, oats, alsike clover, certain grasses, and potatoes, are considerably more tolerant than others, such as barley, sugar-beet, or mangolds. Further leaching and removal of the calcium ion leads to the changes comprised in the term 'podzolization', the considerable changes in the clay nucleus studied by Gedroiz whereby it loses stability and becomes liable to attack by the acids formed from the decomposing organic matter. So the surface layers of the soil lose calcium, magnesium, and iron, and somewhat smaller quantities of alumina and silica. These are carried downwards by the percolating water and are precipitated as the result of complex changes not yet understood. If the process goes far enough a podzol results: the soil constituents separate out and definite layers are formed; the uppermost one consists of black acid humic material, below is a bleached and washed-out layer, and below that again is the layer of deposition where the soluble material removed from above is precipitated and may indeed form an impermeable layer. The podzols are among the most infertile of soils. The remedy is to bring about once more complete mingling of the soil constituents and rebuilding of the crumbs by deep ploughing, &c.; the mixing must be done mechanically, and the crumb formation by adding sufficient lime to give the necessary calcium cations and then putting the land as soon as practicable into a clover or mixed seeds ley. A good deal of reclamation of this kind of soil has been done in Denmark. Methods have been devised for estimating the amount of lime that must be added: after

this is put on the soil must be worked skilfully till the various components have got well mixed up, and then it is cropped, clover and grass mixtures playing an important part in the scheme. Here, as in other cases, it is undesirable to add more lime than is needed, and methods have been devised for estimating the necessary amount. Excess does no good: it is liable to loss by leaching, and it may throw out of action some of the elements essential for plant growth. Crops grown on certain Dutch and German moorland soils, reclaimed as set out above, were found to suffer from an obscure disease which was called 'Reclamation disease' (*Urbarmachungskrankheit*). The cause was ultimately traced to copper-deficiency: the remedy was to supply a small quantity of copper sulphate per acre. Over-liming has also been indicated with considerable justification as a cause of boron deficiency for sugar-beet, and manganese deficiency for peas and certain other crops. Beyond the small reserve of calcium carbonate needed to maintain the calcium cations on the clay and the humus there seems no advantage in having more.

SOIL EROSION

Another type of destruction of soil fertility, also resulting from the breaking up of the soil crumbs, is seen in regions where there is a long dry period during the year, and particularly where, as not infrequently happens in such conditions, there is a liability to high wind or torrential rainfall. Here the native vegetation consists usually of grassy herbage and low scrub, the long dry period being unsuitable for trees. So long as the vegetation cover is left intact it ensures the formation of the granular structure and it protects the soil against mechanical destruction by rain; the soil thus remains *in situ* and it retains its productiveness. But when the vegetation cover is by any means destroyed this protection goes: the heavy rain pounds up the soil and washes it away. Cultivation leads to oxidation of the organic matter and thus to disintegration of the granules, and this action is intensified by the practice of fallowing adopted by farmers in order to con-

serve moisture in the soil and so secure rainfall from two seasons for their crops. As the crumbs disintegrate they fall to dust which easily blows away. Thus the erosion can be brought about in two ways: by wind, when it is often called 'soil drifting', or by water; and there is another division, sheet erosion, where the surface is level or only slightly undulating; and gully erosion, which takes place on sloping land, when the effects may be dramatic in their intensity, the water gathering force as it runs downwards and scooping out great rifts which may be many feet deep.

Wind erosion may be particularly disastrous because it not infrequently happens, as in Western Canada, that the soil is of solonetz or solod type, in which the surface layer is underlain by a very hard thick band, into which plant roots cannot penetrate nor can implements easily break it up. This becomes the new surface, and it gets beaten even harder by the blowing sand, so that it remains bare, like a rock.

Practically all regions of low rainfall and of torrential rainfall are liable to erosion, but the native inhabitants have frequently adopted devices for minimizing its effects. On the other hand, when a new set of farmers or planters has taken possession they have frequently used methods highly favourable to erosion, and the more intensive their methods the worse the destruction has been.

It is no exaggeration to say that soil erosion, with all the devastation it involves, has been the first result of the impact of Western civilization on the new regions occupied in the last hundred years.

The facts have been faced more courageously in the United States than anywhere else, and no attempt has been made to conceal the seriousness of the losses. The farmers who, in the nineteenth and early twentieth centuries, broke up the prairies adopted the most efficient method known for destroying the soil texture: single cropping with wheat, much bare fallow, and considerable disk cultivation. The soil that had taken many generations to form was reduced in a few years to dust which was

easily blown or washed away. The survey made in 1934 revealed the following losses:

Million acres	*Percentage of total land area*	*Extent of destruction*
113	6	Completely unfit for tillage
170	9	75 per cent. of top soil lost.
791	42	25 to 75 per cent. of top soil lost.
111	6	Moderate to severe gullies.
1,185	63	

The situation in Western Canada is also serious, especially in Saskatchewan and in parts of Manitoba and Alberta: here soil drifting has become an acute problem intensified by a sequence of dry years, but as no full survey has been made no table of areas affected, similar to the above, can be given.

Africa affords notable examples of sheet and gully erosion. In South Africa the gullies or 'dongas' began to form when the veld was occupied for pasturage: the animals eat off the vegetation cover, and by their habit of following always the same track to the water-supply they formed a beaten depression where the rain water could not soak in but ran off, so starting a gully. In East Africa, especially in Kenya, there has been much erosion in the last twenty years, the settlers' methods and the consequences thereof having been very conducive to soil losses. No part of Africa that has been exploited by the white man has escaped. In Australia the deforestation of the headwaters of the river systems, and in India the overgrazing of forest glades and the cultivation of the hill slopes, have led to much erosion. Erosion also occurs in many parts of Russia, in Italy, and in other Mediterranean regions.

In seeking remedies the first step is to discover what factors have caused the erosion and then to devise some

course of action which shall permit of the continuance of some kind of agriculture. A Soil Conservation Authority set up on the lines adopted in the United States appears to be the best way of providing the technical help. The remedies fall into the following groups:

1. *Restoration and maintenance of vegetation cover.* Forests should not be unnecessarily destroyed, and grazing of trees and bushes by animals should be controlled. Single cropping systems, especially of maize, cotton, tobacco, and wheat, are bad: rotations are better and grass is best of all, but it must not be over-grazed. These rules are of special importance in the United States and in Africa. In Western Canada emphasis is laid on the fact that unploughed fallows are preferable to cultivated fallows, and should be inserted in strips in the cultivated areas, rather than left in one large piece.

2. *Reduction of 'run-off' of water.* Cultivations should be along and not down the slope: land should be terraced either by the broad 'Mangum' terraces of the United States, the 'bunds' of India, or the walls adopted by the vinegrowers of Portugal, Italy, and other European or Eastern countries.

3. *Protection against wind.* Belts of trees should be established as wind-breaks.

In the British Empire the carrying out of the necessary provisions often presents grave administrative difficulties. Treaties made with native tribes permitted methods which were innocuous in the times when populations were small, but have become very harmful now that the human and live-stock populations have so much increased under British rule. These difficulties account for some of the delay in dealing with the problem.

But it is of special seriousness for us, who hold within our Empire so much of the world's surface, thereby taking upon ourselves the responsibility for conserving its soils for the use of future generations. A survey of the soil resources of the Empire is urgently needed.

SOIL SCIENCE: ITS RELATION TO SCIENCE AND PRACTICE

It is often stated that soil science was never an independent subject till recently, but I cannot agree with that. It was certainly included in general agricultural chemistry, but those who worked at it specialized in it and studied it for its own sake. We were all of us, of course, in close touch with the big problems of agriculture, and all on the look-out for practical applications of any results we might obtain. The big specialized research institutes, with staffs selected on scientific attainments only, sometimes free from any knowledge of or contact with the problems of practical farming, had not yet developed. But all this was coming, especially on the Continent, and with it the claim that soil science should be an independent 'discipline', to use the Middle English word adopted by the acolytes of the new order at home and abroad. And, as a science must have a Greek name, it was called Pedology. Unfortunately the name lacks the first essentials in nomenclature: clarity, and freedom from ambiguity. American writers had already used it for the education of children, while even at a British Association meeting, where it must be assumed that vulgar errors never arise, a 'pedological excursion' attracted a certain number of expectant people who thought it was a high-brow method of designating a walk. Personally I have never felt drawn to its name and have never willingly labelled myself a pedologist, though I admit that the usual expression 'a soils man', while quite clear, lacks dignity. Unfortunately I cannot think of a better term.

Every scientific investigation must be carried out in accordance with the rules of the game, and freedom to follow up any promising line, whether there be practical implications or not, is one of the first of these. But the relations between the soil and the growing plant are so close that it is impossible to get far in any soil problem without coming up against the plant: in some form or another soil fertility is always obtruding. Moreover, particularly in England and Scotland, there are highly

competent farmers and growers who are remarkably good observers, and who have a fund of empirical knowledge on which we have hardly yet begun to draw, and which we certainly cannot explain. We are shirking our responsibilities to this generation, and also losing valuable material, if we shield ourselves behind the claim that Pedology is an independent science and has nothing to do with practical farming. One of the great merits of Hall's own work is the contact which he has maintained with the land itself, and he has always urged soil investigators to keep in close touch with good practical farmers and gardeners, and, side by side with the fundamental work, to have some of their problems under investigation, even if only empirical methods are available for finding solutions.

GRASSLAND

By SIR R. GEORGE STAPLEDON

'So that all life, animal and vegetable, seems in its essence like an effort to accumulate energy and then to let it flow into flexible channels changeable in shape at the end of which it will accomplish infinitely varied kinds of work.' HENRI BERGSON.

'The great areas of grassland have a lower output of energy than the cultivated land.' SIR A. DANIEL HALL.

THERE are two avenues of approach to the consideration of the huge acreage of grassland in this country. We may consider the grassland as such, its present condition and the methods most appropriate to the improvement of the poorer types, or we may look on the area under grass as so much land and inquire whether it is in the best interest of the nation, and of the farmer, to retain so vast an acreage locked up in permanent grass. In short, we are in a position to take into account both actualities and potentialities. To-day, as perhaps never before, it is of the first importance in all matters relating to agriculture to look forward and devote all our energies to potentialities, for the practices of farming over the larger area of the country are not in accord with the needs of the times nor with the knowledge and facilities at the disposal of the farmer. With this view, as applied particularly to our grassland acres, Sir Daniel Hall himself would assuredly agree, for if the Land Improvement Commission which he so strongly advocates were brought into being, that Commission would find itself chiefly concerned with farms and estates consisting predominantly of derelict grassland.

Looking at grassland from this standpoint the quotations at the head of this article, the one from Henri Bergson and the other from Sir Daniel Hall, afford admirable and complementary texts for our present discussion. Energy applied to the practices of farming and devoted to the evolution of new methods, all designed to use to maximum advantage the energy that lies latent in

the soil, that is what is needed. Let this but be realized and acted upon to the full, and the reward is self-assured, for 'Energy is eternal delight'. Grassland constitutes an immense store of potential energy, but almost invariably it needs some help and some assistance even before it will render up a reasonable quota of that energy in terms of its own leafage; but most usually the full energy-value can only be obtained from grassland by ploughing it up and using the sod to nourish and hold a variety of successional crops. Amongst these successional crops can be the sward itself (developed from leys)—with all the energy-giving advantages associated with turf or sod. So that, in fact, we have three alternatives before us in dealing with permanent grass: firstly, we may set out to improve it; secondly, we may set out to banish grass completely, or almost completely, and devote areas now wholly in grass to the most intensive form of arable farming without any dependence on the ley at all, or making use only of the arable or one-year ley. Thirdly, we may base our system on the longer ley (of a duration of two or four years, or even longer), and embark upon a system of alternate husbandry, or of ultra-modern and scientific ley farming.

We are only here concerned with the first and third of these alternatives, but to consider the two in which we are interested at once raises a point of extreme importance, and one that has received but scant attention, namely, the relation of the condition of permanent grass to the energy-potential that will be released when permanent grass is ploughed out with a view to initiating a system of alternate husbandry or of ley farming.

All too frequently when we turn our minds to the consideration of grassland we think only of the herbage or the leafy ration that presents itself to the grazing animal. That is, however, only one half of the picture; the other, and equally important, half is the sod that produces that leafage.

From the point of view of energy-potential, the sod is the essential part of grassland, and therefore it is to the sod that we must now devote our attention. Great as is

the variation between all the manifold types of grassland, both semi-natural and tended, that contribute to our grazings, meadows, and pastures, the variation amongst the sods beneath these herbages is greater still. These sods will vary amongst themselves not only as the direct result of the species which are primarily responsible, but also as a result of the management of the swards to which they give rise. Thus, the sod below an undergrazed *Agrostis* pasture almost wholly devoid of white clover and with but few deeper-rooted weeds will be entirely different in appearance and in energy-potential from one overlaid by a well-grazed *Agrostis*–white-clover pasture. Not only will the former sod be of much lower energy-potential than the latter, but only very slowly and reluctantly will it release such energy as is locked up in its closely matted fabric. To examine a large number of sods dug up from grazings and swards of contrasting botanical composition and variously managed is to be impressed with the immense differences which show themselves. Densely matted sods consist of an overwhelming proportion of completely dead roots and of the accumulation of completely dead leafage—all this completely dead, but fossilized as it were and not completely rotted. The sods below a vigorously growing herbage consist of an admixture of rotting material and actively living and fibrous roots, and in proportion as the latter predominate over the former so is the energy-potential high and the more easily rendered of immediate productive use.

The amount of energy locked up in matted and fossilized sods can be shown in a variety of ways other than by the crop yields that will follow upon the complete aeration and rejuvenation of such sods by either heavy dragging and harrowing (when the crop yields will be the direct product of the swards appertaining to the sods themselves) or by ploughing up.

For example, manurial experiments conducted by Fagan and Davies (1931) have shown that as the result of applications of soluble nitrogenous manures added to poor upland swards (devoid of clover), overriding matted sods,

a greater amount of nitrogen has been yielded up by the herbage offering than could possibly be attributed to the amount of nitrogenous fertilizers actually applied. Moreover, this extra recovery of nitrogen resulting from the application of the fertilizers appeared to be in more or less direct proportion to the amount of organic matter (sod) in the soils. Thus it would seem that the application of the inorganic nitrogen to some extent unlocked the stores held in the sod. Such stores were, therefore, in the sod to be unlocked.

Considering P_2O_5 as a further source of energy-potential, we are able to obtain evidence of the locking-up process. Thus Hanley (1937), discussing chemical evidence from the long-continued Cockle Park experiments, remarks: 'Forty years of grazing at Cockle Park has resulted in the removal in livestock of only about 8 per cent. of the added P_2O_5. The remainder has accumulated in the surface soil to a greater or less extent, according to the fertilizer used'; while in terms of a number of hay experiments conducted the highest percentage recovery of P_2O_5 (over four years) was 32 per cent. Experiments conducted by Davies and Milton (1939) on *Molinia* and fescue dominant sods on the Welsh hills have shown a phosphate recovery of about 18 per cent. in the grass clippings removed, while it was also shown that the recovery was increased, by the addition of limestone, to as much as 30 per cent. on the *Molinia* area, and 24 per cent. on the fescue area.

The point arises as to whether the P_2O_5 locked up in the soil has occasioned an energy-potential less than its own inherent worth, the same as its own worth, or greater than its own inherent worth. This is a matter of considerable academical interest, but for our present and practical purpose suffice it to say that sods which have been heavily phosphated, which have become full of clover, and which in consequence have been well grazed, because of the combination of all the factors which the original application of basic slag (P_2O_5) has brought into play, will have become possessed of an altogether higher energy-

potential, and one much more easily rendered fully effective (by heavy dragging or ploughing), than that appertaining to the original and untreated sod.

This naturally brings us to a consideration of clover, and of white clover in particular, as a source of energy-potential. We have interesting evidence of the current and manifest energy-potential occasioned by white clover from live-weight-increase experiments conducted by Iorwerth Jones (1936). On an eight-acre field different simple mixtures were sown in 1931. One series of plots was sown with grasses only (rye-grass and cocksfoot) and another series with wild white clover added to the grasses. The field was not particularly propense to volunteer white clover, and only comparatively little clover came into the non-white clover plots. Live-weight increase was recorded with sheep on the several plots for four consecutive grazing seasons (1932–5). The average total live-weight increase for the four seasons was 777 lb. per acre from the non-clover plots, and 1,001 lb. per acre on the corresponding with wild white clover plots—a difference of approximately 29 per cent. in favour of the plots in which wild white clover contributed in full measure to the sward. In the third grazing season the advantage with the clover plots was actually as high as 50 per cent. in excess of the grass-only plots. This evidence is exceptionally reliable and trustworthy, becase as many as 110 sheep contributed to the data each year over the four-year period, and, as we have said, unsown white clover interfered with the experiment to an extent which was negligible. In addition to the increased live-weight from the with-clover plots the carrying capacity was 15 per cent. greater than on the grass-only plots, a point the significance of which will be dealt with presently. That the current and manifest increase in energy-potential of the sod (seen in the crop of its own production) resulting from the action of white clover carries over into a rotation in the event of the such-clovery sods being ploughed out is rendered all too apparent at the Welsh Plant Breeding Station, where great difficulty is experienced in levelling up the fertility of fields that

have carried seeds-mixture experiments involving little and much clover respectively on the several plots.

This carry-over is also demonstrated by experiments conducted by Davies and Chippindale (1935), who have shown by pot experiments that the reserves of nitrogen were higher in the soil upon which clovers were grown than in those upon which grasses alone were grown. Experiments conducted by Johnstone-Wallace (1937) at Cornell, U.S.A., throw further and important light on the influences of white clover on energy-potential. He has shown that white clover, as well as increasing the gross yield of herbage, exercises a certain and real influence on soil temperature, and also exercises a control on water relationships, for it 'greatly reduces the loss of water by run-off from the surface during heavy rains'. Thus this plant has an important part to play in the prevention of erosion, and therefore by this much also on energy-potential.

Red clover, like white clover, exercises a pronounced influence on energy-potential: thus Davies (1939) has shown that the inclusion of Montgomery red clover in mixtures, both for hay and for pasture, has not only increased the gross yield of herbage by its own contribution to such herbage, but has also had the effect of increasing the yield of the grasses themselves. Thus in first-harvest-year pasturage the percentage increase in gross yield due to red clover was 46 per cent., while the percentage productivity of the clover itself was only 30 per cent.

It is more than probable that not only do the clovers and other leguminous plants exercise a favourable influence on energy-potential, but that such influences are also exercised at least with different specific intensities by the several grasses and miscellaneous herbs—directly and indirectly.

Davies and Chippindale in connexion with the experiments previously referred to have demonstrated that both grasses and wild white clover tend to lower the acidity of the soil; the effect of the grasses apparently being somewhat greater than that of the clovers, while the magnitude

of the effect is more or less proportionate to the growth of herbage. It would thus seem that any treatment of a sward which encourages grasses with a high and sustained yielding capacity at the expense of those with a lower capacity would as such react favourably upon energy-potential. Furthermore, the greater the yielding capacity of the sward the greater the stock-carrying capacity, and therefore by that much greater would be the urine and droppings deposited upon the sod. To this question we will presently revert, but a few remarks should first be made relative to the influence of miscellaneous herbs.

The feature of miscellaneous herbs which is of prime importance in connexion with energy-potential is the fact that many of them display marked differences in chemical composition from that of the grasses and clovers. From the point of view of biochemical ultimates the full extent of these differences has not yet been ascertained. We know, however, that certain herbs much relished by stock growing on soils far from rich in phosphates, or in lime, none the less contain in their leafage large amounts of the essential minerals concerned—far larger amounts than do the grasses or the clovers.[1] The herbs, in consequence, extract elements from the soil in a manner quantitatively different from the grasses and clovers, and they may do so also in a manner qualitatively different. These various elements, to a large extent, will be returned again to the sod, either via the direct rotting-back of the plants concerned, or via the grazing animal. In either event the elements will not be returned in precisely the same molecular company as that in which they previously existed in the soil. It would necessarily follow, therefore, that the presence in swards of herbs with a biochemical make-up widely different from that of the grasses and clovers must exert a considerable influence on energy-potential, more particularly by their specific reaction to the soil and their influence on the precise and biochemically ultimate character of the urine and droppings of animals eating their leafage. The influence of these herbs, moreover, if not

[1] See, for example, Fagan and Watkins (1932).

present to excess, is almost certain to be favourable, for energy revels in complexity and dissimilarities. And so 'the earth the true mother in whose bowels is more wealth than ever will be drawn forth'.

We have now to consider what is perhaps the most important of all sources of energy-potential, or at all events the most important source relative to rendering such potential immediately manifest—we refer to the urine and droppings of the grazing animal. Here again we will have to translate our productivity evidence in terms of the herbage directly produced by the sod itself. Experiments conducted by Iorwerth Jones (1934 and 1935) provide strong evidence. On swards that had long been down to grass he set up plots to test different systems of management based on various schemes of cutting and various intensities of grazing. Save for an initial and uniform dressing of basic slag over the whole of the experimental areas no manures were used, and the only differential treatments were those of management. After continuing the several treatments for four years, accurate yield and botanical data were obtained, with a view to assessing the cumulative effects of such treatments. Our only concern here is with the yield data, and the statement hereunder sets out comparatively (with the yield from the plots grazed hard during the spring put at 100) the results obtained from the average of two of the trials.

Hard grazing during the spring only	100	96·3
” ” summer only	97	
” ” autumn only	94	
” ” whole grazing season	94	
Moderate grazing: grazed every month	89	88·5
Lenient grazing: grazed every two months	88	
Mown every two months and herbage not removed	69	66·0
Mown for hay and aftermath	69	
Mown every two months and herbage removed	60	

It will be noticed that the lowest yields were obtained from the mown plots on to which animals were never introduced, while the heaviest yields were obtained from the hard-grazed plots. Looking more closely we shall

see that the hard-grazed plots gave very appreciably higher yields than those grazed more leniently, but that the plot grazed hardest of all (hard grazing throughout the season) gave a slightly lower yield than plots grazed hard during only the spring or the summer. Thus save for the hardest grazing of all the yields were directly proportionate to the intensity of the dunging and urination by the animals. This is the more interesting because the yield from the plot upon which the herbage was allowed to rot back after each cutting was less than that obtained from any one of the grazed plots, including the plot that was grazed on a parallel intensity with the cutting on the rot-back plot. The conclusion, therefore, forces itself upon us that herbage returned to the sward via the grazing animal has a considerably greater effect on energy-potential than has similar herbage left to rot back unaided. If this is, in fact, a just generalization, and the whole of our long experience of grassland inclines us to believe that it is, then we have reached a practical conclusion of the first importance, namely, that to leave pasturage ungrazed on a field constitutes a double waste, a waste of ration never converted, and a waste of so much energy-potential that might have been returned to the sod; while the evidence stands witness in the most unmistakable manner to the high energy-potential of the urine and droppings of the grazing animal. The evidence of this is even greater than the figures under review suggest, for previous experiments have shown that when defoliation is effected by shears or mowing-machine, and the herbage removed, the yield progressively falls as the number of defoliations is increased beyond two, or at the most three, cuttings.[1] On an old sward consisting chiefly of the species less impaired by repeated defoliation (perennial rye-grass, *Agrostis*, and white clover) it is, however, only when very hard grazing is continued throughout the season that the influence of defoliation begins to assert itself, despite excessive urination and dunging by the animal.

Evidence of a different, but equally informative, charac-

[1] See Stapledon (1924).

ter has been obtained from an experiment still in progress, and the data which we shall now consider have been prepared by Mr. William Davies, who is in charge of the experiment in question.

On an area sown down in 1933 with a mixture consisting of Aberystwyth-bred strains of grasses and clovers, and of other leafy strains, plots were arranged to test the differential effect of 'day' and 'night' paddocking, for it is known that animals excrete more at night (including dusk and dawn) than they do in the day proper. The magnitude of the differences brought about in gross yield of herbage is demonstrated by the statement below.

Duration of differential treatment	*Mid-season yield per acre from 'night' paddock*	*Yield of 'night' paddock expressed as a percentage of 'day' paddock*
1934–5	646	173
1934–6	1,458	291
1934–7	1,132	205

Taking the three seasons together the yield from the 'night' paddock has been over twice as great as that from the 'day' paddock, while during the growing season of 1936 when herbage yields everywhere were high the 'night' paddock gave practically three times as heavy a yield as the 'day' paddock. The beneficial effect of dunging and urination is therefore proportionate to the yield of herbage offering and converted. It is proportionate, too, to the quality of the herbage offering and its effect is cumulative, cumulative because herbage plants are peculiarly sensitive to the fertility status of the soil, and as this is graded upwards so will such plants as are responsive to heightened fertility-level, and as may be present in the sward, gain rapidly on the low-fertility plants previously dominant. While as fertility further increases (that is to say, as energy-potential becomes higher and is also rendered manifest) plants appropriate to such higher levels of fertility will gradually make their appearance—arriving from where, and how arriving, no man can with certainty

say[1]—and then after the lapse of a further period it will be these welcome volunteers which will perhaps dominate the sward. We shall then have reached an entirely different range of levels, a herbage at once more productive and richer (in protein and minerals), carrying more stock, and because carrying more stock the return in urine and droppings—both greatly enriched—will be enormously increased.

We have followed and recorded all these changes in detail in connexion with our experiments both at the Welsh Plant Breeding Station and on the lands of the Cahn Hill Improvement Scheme. Peculiarly informing are the differences between the camping-grounds—in effect 'night' paddocks—on one of the open hills taken in hand on the lands of the Scheme, and on a neighbouring open hill where no improvements have been effected. On the improved hill, patches of sward have been created consisting wholly of wild white clover and the better and more productive grasses, while all the areas giving rise to these patches have been heavily phosphated, and some also limed. On the unimproved hill there are no such protein and mineral-efficient patches. Sheep graze improved patches heavily during the daytime; towards evening they tend to wander away on to the unimproved areas, and later camp in relatively sheltered places towards the hill-tops. The camping-grounds on the improved hill show unmistakably the benefits of the richer dung and urine there deposited. *Agrostis* (a much higher fertility-demander than sheep's fescue, white grass (*Nardus*), or the various non-gramineous plants proper to such vegetation) becomes absolutely dominant, and over wide areas plants like yarrow and smooth-stalked meadowgrass (neither sown on the improved areas) begin to make an appearance; with these may also appear ribgrass and other herbs. In short, the flora is more extended, *Agrostis* more aggres-

[1] A number of plants, in fact, make entry of which it is true to say that direct evidence shows that buried viable seeds of the species concerned were not present in the soil or sod underlying the original vegetation. See Milton (1936).

sive, and the productivity higher on camping-grounds of the improved hill than on those of the unimproved.

Evidence obtained from manurial trials conducted both on natural *Molinia* swards and on natural fescue-bent swards affords further and conclusive proof of the trend of events we have narrated. A large number of long-duration manurial trials have been conducted, some in the presence of the grazing animal and others on areas from which the animal has been totally excluded. Without

Gain in dry-matter yields obtained from ungrazed and grazed plots as a result of initial dressings of basic slag and lime per acre in 1931

Manuring	12 *cwt.* *basic slag*		5 *cwt.* *basic slag*		12 *cwt. basic slag*+1 *ton limestone*		2 *tons limestone*	
Management	*No grazing*		*Free grazing*		*No grazing*		*Free grazing*	
Type	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*	*Molinia*	*Fescue*
Year								
1934	134	79	349	236	333	100	..	221
1935	223	198	470	258	525	161	88	442
1936	154	113	652	771	309	131	724	1,421
1937	143	107	582	897	320	107	880	1,751

exception, establishment and spread of the higher-fertility demanding species, when sown, have been seen to much the best advantage on areas to which stock have had access. Even more interesting is the fact that volunteer entry of such plants as wild white clover, rough-stalked meadowgrass, smooth-stalked meadowgrass, mouse-eared chickweed, yarrow, and a number of herbs on areas upon which no seed has been sown has been much greater on the with-sheep than on the without-sheep plots, while on the with-sheep plots the more aggressive of these species rapidly and successfully contest dominance with *Agrostis*. The result is that in terms of yield of herbage the with-sheep plots show to marked advantage over the without-sheep plots, and this, be it noted, even when both series of plots have been generously manured with CaPKN.

Davies and Milton (1939) in their most recent paper are able to bring forward striking evidence relative to yield, and with grateful acknowledgement to the authors and to the Editorial Board of the *Empire Journal of Experimental Agriculture* I here reproduce a table of evidence taken from that paper. It is true that neither nitrogen, as such, nor potash had contributed to the scheme of manuring brought under review, but this is immaterial, for potash is not of much significance on the areas we are considering, while since the plots in question were sown with wild white clover in conjunction with grasses, and since wild white clover was an abundant contributor to the sward, there was manifestly no lack of available nitrogen in the sod. There is no question as to the magnitude of the influence from the dung and urine of the grazing animal, and here we have culminating evidence in support of all we have brought forward as to the almost overriding importance of urine and dung in relation to the energy-potential of the sod.

It is beyond the scope of our discussion, and would serve no practical purpose, to carry our evidence into the vortex of the CaPKN *versus* 'organic' controversy, and in relation to the biochemical intricacies which that controversy necessarily embraces. We are concerned only to say that here is a mass of evidence that indicates that urine and dung in the sum of their influence on energy-potential (an influence that shows itself amongst other, and no less important, ways in the readjustments made in the botanical composition of the sward) are competent to bring about results that applications of lime, phosphates, potash, and nitrogen either alone or in combination are incapable of bringing about in the absence of the grazing animal.

The fundamental and practical conclusion to be drawn is this: That urine and dung to be of maximum benefit to the sod must have been the product of a herbage that is at once plentiful and of high nutritive value. Consequently, any aid, either mechanical or taking the form of the sowing of seeds, or of the application of inorganic fertilizers, or of the feeding of concentrates to the animals grazing the sward, that will tend to add to the quantity

and quality of the herbage will add also to the quantity and quality of the urine and dung. The rationale of grassland improvement aiming primarily at sod-enrichment, and the enhancement of energy-potential, is to initiate an ever-widening cycle of wholly favourable and interdependent movements and changes. Such a cycle Mr. Hosier initiates, and most admirably initiates, by his bailing system; Somerville initiated his cycle by heavy applications of basic slag; others have initiated the cycle by heavy and drastic harrowing or dragging, and yet others by a combination of heavy dragging, slagging, and the sowing of seeds of wild white clover, while more recently drastic sub-soiling has been adopted with great advantage. No matter, however, by which means the cycle is initiated, all aim at the same goal, although perhaps not quite realizing at what goal they are precisely aiming, namely the heavy and uniform spread of the maximum quantity of urine and dung of high quality (the precise definition of 'high quality' in terms of biochemical ultimates remains, and is long likely to remain, a baffling problem for the biochemists) per unit of area.

We have now reached the core of our whole argument, because we have arrived at the point where we can see that the improvement of grassland must concentrate on the sod, for the sod in very truth can be described as the soul of the soil, the hidden source of most of its energy-potential. Moreover, we can see further that if it is desired to plough up old sod, the outcome of outrun and derelict sward, with a view either to initiating a system of alternate husbandry or ley farming, or, for that matter, of immediately establishing a new and better sward, it is highly desirable to have improved that sod (and therefore also the sward) so far before ploughing down, because of the truth that one should 'never sow a crop unless there is condition to grow it luxuriantly'—unless, in fact, the soul of the soil is healthy and of high energy-potential.

To hold to our theme we must now briefly consider the means of improving very poor grassland with a view primarily to adding to the energy-potential of sod

preparatory to ploughing it down. It so happens that in most respects the methods applicable to the improvement of permanent grassland are the same whether we are primarily concerned with the sod or with the herbage, so that what follows will not be wholly without interest to the man who is wedded without fear of divorce to permanent grassland.

At the very outset it is desirable to make abundantly clear what our aim should be. Our ultimate aim—and Sir Albert Howard in particular please note, and the followers of Rudolf Steiner will not be uninterested—is to make and spread with the least possible trouble and expense a highly efficient compost all over the field upon which we have decided to operate. Compost, no matter the precise methods of making it, always depends upon mixing together earth, lime, and animal and vegetable residues, and compost will be efficient according as everything has nicely rotted down—will be efficient, that is to say, in direct proportion to the extent of the re-shuffle and re-marriage of atoms and molecules.

In effect, then, our major aim in the preliminary grassland improvements which we should endeavour to accomplish will be a wholesale re-shuffle of atoms and molecules preparatory to the final act of composting and spreading, which will be the ploughing, the liming of the upturned sod, and the harrowing down. If there is one thing more than another which we have learned from all our experiments and experiences gained during the last twenty-six years it is the aptness of the dictum so often propounded by J. L. Garvin relative to affairs of State, when applied also to the improvement of grassland: 'First things first.'

Seldom, indeed, is it that one action of itself will do much to improve a very poor sward; always several actions must be taken, and these in their proper order; and the proper order of procedure in its simplest form nearly always is as follows:

1. Render the fences stock-proof.
2. Bring drinking-water to the field.
3. Attend to drainage.

4. Get rid of all roughage.
5. Scratch and drag heavily.
6. Apply lime.
7. Scratch and drag heavily.
8. Apply basic slag, and, if necessary, sow the seeds of wild white clover.
9. Scratch and drag heavily.

We will start our more detailed discussion with No. 4: 'Get rid of all roughage.' In the case of the poorest and roughest swards and most heavily matted sods, one year, or two years, may usefully be devoted to the clearance of roughage. A good plan is to start with the fire stick, and then, immediately growth returns, to introduce hungry cattle, or, if available, a large head of ponies. The influence of stock will be increased in two ways if at this stage the field is given a light and complete manurial dressing, say 5 cwt. ground limestone, 5 cwt. basic slag, and $1\frac{1}{2}$ cwt. nitro-chalk. The effect of this light dressing will be primarily to make the rough herbage more palatable to stock, and, incidentally, it will also increase the amount of herbage and will act favourably on both the quantity and quality of the urine and droppings of the animals.[1] The aim should be to introduce as large a head of stock as possible at each grazing, so as to effect as even grazing as possible, and as even spread of urine as possible. The endeavours of the animals must be supported by the mowing-machine on all occasions possible, and the inflorescences of the poor grasses must not be allowed to appear, nor must buttercups or other weeds be permitted to ripen seed. The mowing-machine, the direct successor of the scythe, is, indeed, to be regarded as perhaps the most important implement to be used in connexion with the improvement and management of grassland. How long the major truths of good husbandry—even good grassland husbandry—have been recognized, and yet how little acted upon! In 1762 Stillingfleet remarks, relative to rye-grass: 'but

[1] Experiences gained on the lands of the Cahn Hill Improvement Scheme have abundantly proved the value of adopting this (manurial) aid to the clearance of roughage.

unless swept over with the scythe its flowering stems will look brown, which is the case of all grasses which are not fed by a variety of animals'. Then, in 1788, that most astute of observers, Marshall, commenting on good practice in Gloucestershire tells us: 'Here not only weeds of pasture grounds are topped generally once, and sometimes twice, but the grass . . . is mown. Several loads of good fodder will sometimes be got off a ground by this practice. . . . Besides the loads of fodder which are obtained, several acres of autumnal pasturage are probably gained, or in other words, fresh ground is added to the farm by this operation.' And, Mr. Marshall, as we are sure *you* appreciated, several tons of rich urine and droppings would have been added to those 'new' grounds. Roughage must be removed, for no improvement can be effected on the sod until this is done: the over-topping vegetation prevents the ingress or the spread of the more valuable, more nutritious, and higher-yielding species, while at the earliest possible moment urine and droppings must be brought to bear upon the sod.

Roughage out of the way, then the tines of dragging implements will be able the better to tear into the sod, and the preliminary draggings and scratchings cannot be too heavy. Aeration to hasten the rotting processes is the aim, and then lime to hasten those processes still further. Lime is to be applied both to satisfy any ascertainable lime requirement and to assist in the making of compost, for the making of compost will have commenced with the first stroke of the dragging implements. We desire to mix lime through and through the sod, and that is why we advocate its application during the preliminary surface cultivations and improvements, and again on the upturned sod when the sward is improved sufficiently to be ploughed out. To apply lime on any permanent grassland without heavy dragging is at the best greatly to delay action, and because of uneven spreading may render the herbage relatively unpalatable for some months, while not to drag, and drag again, when it is the sod we are attacking, is to neglect the most essential operation, and to deny ourselves the

very benefits we are seeking. The whole point of lime is to get it to work on the sod; nitrogen will then become more readily available, the grasses will grow away better, thus more urine and more droppings, and until these things happen nothing happens. Lime has a further, and perhaps not sufficiently realized, ameliorating influence as such: it favours the better and more productive grasses—perennial rye-grass in particular—and on this account, too, its early application is to be advocated. By now the sward will be a living thing, and can be closely grazed, and so the way is clear for basic slag and for white clover to run riot. The culminating essential is that white clover should, in very truth, run riot, for nothing so assists in the rotting down of the mat, and in holding animals to a poor sward, as an abundance of white clover. Often and often the whole sequence of improvements comes to almost nothing because either basic slag has not been applied generously enough and/or because there is no white clover in the old sward and no buried viable seeds in the sod—then the seeds of wild white must be sown.

Our experiences in connexion with the Cahn Hill Improvement Scheme have proved conclusively that the geographical range of the usefulness of slag can be extended into the most unpromising regions if dressings of up to wellnigh 20 cwt. are used, and if these are supported by the sowing of the seeds of wild white clover. It is a somewhat remarkable fact that, save for Yorkshire fog, and, to a more limited extent, crested dogstail, the seeds of the grasses do not establish well on an old turf unless the dragging has been so drastic as to occasion a tilth not far short of what could be achieved by ploughing. Such drastic dragging can be accomplished by a rotary cultivator worked off the power take-off of a tractor, or by pitch-pole and Aitkenhead-ripper drawn together almost scores of times across the sward by a sufficiently powerful tractor. Wild white clover, however, supported by adequate dressings of phosphates, will establish itself from sowing on the most inhospitable of sods without any cultivations at all, provided roughage is kept completely in check.

By the adoption of the sequence of processes we have described, or by adhering more or less closely to them, the most astounding improvements have been effected on isolated and scattered farms all over the country. Here a man may be helping things forward by feeding cake to his young animals, another by carrying out hay or roots, another by actually bailing; but starting from the most matted and most evil of swards the most striking results are to be seen where the farmer slags generously, and at properly repeated intervals drags and harrows heavily with tractor-drawn implements, and with a thoroughness and frequency that would seem to be born of a frenzy of anger —fury is the only proper approach towards an utterly useless sward. By adopting only these means, and sowing never a seed, the poorest of *Agrostis*-fescue pastures have been converted on some farms into valuable rye-grass–*Agrostis*–white-clover pastures. What has interested us very much, however, in the most startling improvements that we have seen is that never has the practitioner in question ceased to use his dragging implement, no matter how far he has carried his improvements. To get from a hopeless fescue-*Agrostis* pasture, and perhaps one containing some *Nardus* as well, to a good rye-grass–*Agrostis*–white-clover pasture by the means we are considering must necessarily take time, seldom less than perhaps ten years, but the pasture will be improving all the time from the moment it is first taken in hand, and will be paying for the necessary operations almost as they are being performed. Generally speaking, to have carried the improvements far enough to warrant ploughing, and the last processes in the making and spreading of our compost, would take about four or five years.

A few words may usefully be added relative to these last processes before we argue the case for ploughing. We should by now have collected together in our sod all the ingredients necessary, save for the need of more earth and some more lime, for a first-class compost. There should be no great amount of 'fossilized' vegetable matter left; there should be an abundance of fibrous and living

roots, an abundance of clover root and clover nodules, and the whole will have been well impregnated with urine and dung. The only question which arises is how to apply the further amount of lime that is necessary, and in what form. If the lime-requirement is high, and most usually it is in such cases, there is much to be said for applying the necessary amount in two dressings, the one spread over the turf before the sod is ploughed up, and the other on the upturned sod to be harrowed in during the cultivations preparatory to preparing a tilth. By adopting such a plan the lime will be the better mixed through all strata of the sod, and the processes of the re-shuffle of atoms and molecules the more hastened. When it is proposed to sow a seeds mixture direct upon the upturned sod in order to create immediately a new and a long-duration sward, ground limestone is the best form in which to supply lime. If possible we should endeavour to supply the lime in such a form, and in sufficient amount, to maintain the lime-status at a proper level for the whole of the anticipated duration of the sward—and that might be eight or ten years. It is just in such cases as these that the arguments brought forward by Rice Williams (1937) in favour of using ground limestone consisting, in part at all events, of coarser fractions than are now usually employed, would seem to be of very special application.

We have now arrived at the point in our discussion where it becomes a question of the balancing of pros and cons, and where personal judgement must necessarily weigh heavily in the scales, so it will be more appropriate at this juncture to lapse into the first person singular.

I have often been asked, Why all this pre-treatment, with consequent delay in the preparation of compost preparatory to ploughing? My answer is twofold: Firstly, because in the long run all our evidence combines to indicate that such is the best and probably the most economical method of effecting the greatest benefits, and this, too, when it is intended to sow down to a new sward straight away upon the upturned sod. Secondly, I am always thinking of the agricultural problem in terms of what I conceive to be in

the best national interest. There are in Great Britain over eighteen million acres of permanent grass, and it is quite evident to me, at all events, that at least 95 per cent. of this huge acreage needs treatment more or less on the lines that I have discussed. How much of that 95 per cent. ought to be ploughed up as a final act in improvement, and how much ought to be ploughed down with a view to bringing it into alternate husbandry or ley farming, I do not at present know. But I do know that on both counts a sane agricultural policy would call for millions of acres, and not merely a few hundreds of thousands of acres, coming under the plough. For to me the two most momentous happenings during this post-War period have been the general rearmament of the nations of the world, and the lapsing of the acres ploughed during the War back to grass, together with the fact that the condition of the permanent grass of this country is to-day very decidedly worse than it was in 1914. Of the two momentous happenings to which I have just alluded—momentous, I think, rather in the sidelight they throw upon the ineptitude of mankind than in the phenomena themselves—it would be difficult to say which is pregnant with the greater potential danger to this country, having regard to the conditions of both peace and war. I can do nothing about all the armaments and counter-armaments, but I could at least do some little something about the closely related problems of all these acres and acres of permanent grass. I want a plan, and on any wise plan all these acres would be scheduled. Those that were to be ploughed would be treated in this way, and the same reasoning would be applicable to any particular farm wholly in poor grassland. The best of the fields (we are only considering poor, bad, and very bad grassfields) would be the first to come under the plough, and in the order of their merit, and starting immediately on the basis of a certain ploughing quota per annum. On the bad and very bad fields pre-treatments would be started immediately, and also on a quota-per-annum basis, and in such a way that the ploughing would be steadily continued, and so that the full programme would be completed according

to schedule. If ever a Land Improvement Commission or equivalent body is set up I do trust that the authorities concerned will remember 'first things first', and draw up a plan based on the immense importance of pre-treatment, and begin not with the worst but with the best (of the poor) fields and with the best (of the poor) farms—I most sincerely hope that Sir Daniel Hall agrees with me in this.

Now to consider the pros and cons of ploughing from a purely agricultural point of view, and quite independently of the needs of the nation as I see those needs.

The argument for ploughing merely as the last act in a scheme of improving a very poor and densely matted sward is primarily this. Time will be saved—one could easily do in five or six years what might otherwise take at least ten—and the way will be made easy to establish a sward superior to that which could be achieved without resort to a complete aeration and breaking-up of all vestige of the mat, and without resort to seeding-out with a modern and well-balanced seeds mixture consisting of sufficient quantities of the more leafy and persistent strains. In this connexion I am sure that Sir Daniel Hall will agree with me that what he wrote in 1913, based on observations made during his pilgrimage of British farming (1910–12), to the effect that 'permanent seeds even when they start away well for a year or two so often become very poor from the fourth to the seventh year', no longer applies, for the science of sward-establishment has moved forward several steps since even so comparatively recently as that.

One of the strongest arguments in favour of ploughing up a very poor grassfield simply as a means of improving the sward (by reseeding) is that by so doing lime can be properly incorporated into the old sod and into the soil. It is probably not far from the truth to say that permanent grass should be ploughed just as often as the lime-requirement of the soil dictates. If for any reason the years of pre-treatment are likely to prove irksome, or too difficult to arrange for, then the farmer, if he so desires, can deal with the sod and build up energy-potential by going through a preparatory and pioneer rotation prior to sowing

down to grass. To adopt such a course is on its own account often to be recommended in the case of the first reclamations conducted on heath or semi-moorland (other than almost pure peat) that has never previously been ploughed. On the poorest of situations Yorkshire fog and ribgrass have been successfully used as the first pioneer crop in connexion with the experiments conducted by the Cahn Hill Improvement Scheme. The essence of a pioneer crop is that it shall give enough leafage to hold sheep and invite urination and dunging, and over as long a grazing period as possible. As a second pioneer crop, or as the first on situations slightly less poor, hardy green turnip and Yorkshire fog have been employed; as a third pioneer crop (or for conditions of higher initial energy-potential) hardy green turnip, rape, and Italian rye-grass may often be ventured upon, and finally, and as or where energy-potential is adequate, rape and Italian rye-grass alone will suffice. A grass is always employed with the crucifer or with the ribgrass to ensure the extended opportunity for urination and dunging—our pioneer crops have given *in toto* from about nine to fourteen months' grazing.

The influence of a succession of pioneer crops on energy-potential is well shown by figures obtained from the most difficult area yet undertaken on the lands of the Cahn Hill Improvement Scheme. The land in question stood at from 1,200 ft. to 1,300 ft. above sea-level, and the vegetation consisted of virgin heather (stunted), bilberry (stunted), *Nardus*, sheep's fescue, and a little *Agrostis*. After ploughing and slagging three pioneer crops were taken in succession: the second was sown on the heavily dragged and harrowed 'stubble' of the first, and the third after a second ploughing and a second phosphating. In the first two cases the crop consisted of hardy green turnip and Yorkshire fog, and in the third, in effect, of hardy green turnip, rape, and Italian rye-grass (actually the hardy greens and rape were sown with a general seeds mixture which included Italian rye-grass).

Data are not available for the full grazing from the three crops respectively, but were obtained in respect of

the lambs fattened in the back-end. The results are as follows:

	Live weight increase in lb. per acre
First crop—the crucifers almost a complete failure . .	16
Second crop—the crucifers not half of a crop . . .	40
Third crop—the crucifers a really good crop . . .	126

From which will be seen the really remarkable influence of pioneer crops used in succession as a means of building up energy-potential under the poorest possible of conditions.

The arguments in favour of ploughing with a view to getting into a system of alternate husbandry, or of ley farming, are many and various, and are, I think, difficult to counter.

In the forefront of these arguments I would like to put the stimulating influence of enterprise upon those who dare to move in advance of the times. Such men, and there are many of them, will appreciate this from that great protagonist of high farming, John Wrightson: '... permanent grass; that is, in other words, the question of the abandonment of agriculture altogether and betaking us to the semi-barbarous occupation of pastoral life. It is rather a sad alternative in a scientific age like this, but it is the tendency.' These words were written in 1888, during the then agricultural depression. We are in the throes of an agricultural depression to-day, but yet things are very different as affecting the possibilities of breaking away from 'semi-barbarous' occupations, in two respects in particular, both favourable to a break-away. I refer, firstly, to the advent of the tractor, cheap fertilizers, and improved and more persistent strains of herbage plants; and secondly, to the greatly extended opportunities open to the modern and progressive farmer for embarking on sidelines, and no mean sidelines at that: poultry, market-garden crops, pigs (indoor and out), and seed-production. One is impressed by the fact, moreover, that sidelines such as these are to be seen at their best on farms operating very largely on the ley basis.

Now for particular arguments, and those of a more strictly technical nature. In the first place, it is much to be doubted if the energy-potential in the sods of the best, or even of reasonably good, permanent swards is ever rendered manifest to the full in terms of the herbage produced by such sods. Or, alternatively, if the sods have done their duty the farmer will not have done his and there will be enormous waste, and then, as I have shown already, if there is waste the sods will not be able to do their full duty. I am prepared to believe that a man farming well, using dragging implements and manures, and supporting his general farming by skilful silage-making or by grass-drying, may use to the full the energy-potential resident in the sods of his good permanent grass. I do not believe it is possible to do so under any other system.

To-day no man who breaks even the richest pasture in the country need have any qualms about the establishment of equally productive swards in terms of long-duration leys on such land, when to do so suits his scheme of husbandry: in this respect the farmers of to-day stand in marked contrast to those of the eighties.

To graze really intensively by modern methods of bailing and folding on permanent grass must inevitably be wasteful of energy-potential; the potential becomes so great that it cannot be rendered manifest without that degree of aeration that only the plough can achieve.

Methods of bailing and folding are assuredly only in their infancy, for such perfect methods of catching urine and dung, and then later (by ploughing) making of compost, must be capable of endless modifications and adaptations, and to bail or fold, except on leys, both on scientific and practical grounds amounts to a contradiction in terms.

When we come to consider the poorer pastures on the poorer lands it becomes apparent, in the first place, that long-duration leys can be established on such land of a standard of productivity altogether greater than that to which the permanent grass could ever be brought; while secondly, with the sods resulting from such good leys high-standard arable crops could be produced. In these days,

when horse and stable manure is scarce, and yard manure itself expensive to produce, the manurial value of sod should be seriously considered by the arable farmer—more particularly so by that type of quasi-arable farmer who is content to be a 'barbarian' on one part of his farm and a farmer on the other. All too often, moreover, the permanent grass on such farms is nothing more than worn-out (and cropped out) arable land, of the sort that Marshall in 1788 declared should be converted 'to a state of profitable sward', and, as he further remarked, to do so 'is one of the most important operations in husbandry, and is perhaps of all the operations the least understood'. The years roll on, and still how true that 'there is sometimes only a paper wall between a useful discovery and the greatest ignorance of the nature of things'. The differences in the practices of farming so often observable if we will only cross a couple of stone walls or hedges are, as I suppose they always have been, one of the outstanding features of the agriculture of all but the most highly farmed districts in this country. The chief reason for this is that the generality of farmers have not the least conception of the value of sod, how to enrich it, or how to use it when enriched. Here my friend Professor G. W. Robinson comes manifestly to my aid when in one of his open letters to me he roundly declares, 'I would go further and preach the temporary ley wherever the plough works',[1] and, say I—I am concerned here only with this little island of our own—'the plough should work wherever it can be made to work'; and in support of these views let me quote the opinion expressed by John Boswell a hundred years ago, who maintained 'that without grass, severely cropped land cannot be restored to full fertility; and without cropping grass cannot be made to continue at the maximum point of verdure and utility'.[2]

The ley itself has many advantages over permanent grass from the point of view of the herbage ration for farm

[1] See Robinson, G. W. (1937).

[2] I am grateful to Principal Boutflour for having brought these and other utterances of Boswell to my notice.

stock. Chief amongst these are the opportunities afforded for the lengthening-out of the grazing-season, while systems of management that as such are bad for a sward can be conducted on a ley, in any event when it is due to be ploughed up within a short period of any particular malpractice.

To discuss in detail either the ley itself, or the rotations that are applicable to systems of alternate husbandry, or of ley farming, is beyond the scope of this article.[1] The point to be realized is that the ley properly used makes it possible and profitable to farm in even wider circles, and over a wider geographical range of country, than Lord Ernle probably had in mind when in 1912 he wrote, 'Farming in a circle, unlike arguing, proved a productive process.'

In all that I have here written it is not to be supposed that I deem it practicable to initiate a system of alternate husbandry, or of ley farming, on all the soils or in all situations where permanent grass prevails. Some soils are too heavy, some fields are too steep, in some districts the restricted rainfall may be a serious limiting factor. With the tractor and modern implements, and granted rotations designed to suit particular and difficult sets of conditions, and granted also methods of sowing-out and establishing leys which are appropriate, then I am persuaded—and on the basis of a very great deal that I have seen—that the acreage in this country definitely unsuited to alternate husbandry or to ley farming is much smaller than farmers themselves, or than statesmen, care to admit. I believe, moreover, that there is no single agricultural fact that is more important to be known in the national interest than the acreage that is self-committed to remain in permanent grass. Of that acreage it is more than probable that a considerable proportion should be handed over forthwith to the forester and made to grow good timber.

I may usefully conclude this article with a few words in explanation, if not in justification, of my method of

[1] See, for example, Orr, John (1937), Fagan, T. W., and Davies, Wm. (1938), Stapledon, R. G. (1937–8).

approach to the various problems involved. I have advisedly adopted the phrase 'energy-potential', and not talked in terms of soil-fertility, or too explicitly or too narrowly in terms of the factors which the scientist deems to influence soil-fertility. There is so vastly much that we do not know about the soil and about plant growth that I have preferred to adopt a useful and workable fiction, and to think of energy-potential as if it were in effect an integral thing.[1] It is herein, I think, that the farmer and the man of science differ so widely from each other in outlook. The farmer is always setting up fictions founded on the widest integration. His fictions are not bounded by known facts. The farmer realizes instinctively that all the circumstances under which he lives and acts, and all the 'laws' of nature, can never be known to him. He realizes too that if he did know them all merely in terms of scientific categorization he still could not know them in terms of their manifold interactions, for 'we know a change only when we are able to determine what it is about at any one of its moments'. The farmer feels his way into understanding as well as learns his way in, and by that much in his judgements relative to the problems of agriculture, which always are the problems of life, he is often worthy of greater attention than is the man of science—although, perhaps, not explicitly known to himself he will have taken more of the myriad of operating factors and complexities into consideration.

My own approach to the problems of that particular branch of agriculture in which I am interested has always been based on a deep appreciation of the importance of all that I do not know, and upon a strong desire not to place too much weight upon the isolated facts with which I have become acquainted. I am sufficiently unscientific, or possibly sufficiently scientific, to permit feeling to colour my 'scientific' judgements and opinions.

[1] See also Alverdes, F. (1932).

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DEVELOPMENTS IN PLANT BREEDING

By H. HUNTER

IN any record of agricultural progress in the British Isles the part played by crop improvement is noteworthy alike by actual achievements and by the legitimate hope of further advancement that those achievements have engendered. In these Islands, of relatively limited area and extremely varying environment, the results obtained lack the spectacular and cumulative features of Continental areas, but they represent nevertheless efforts of close approximation to diversified agricultural and, in some cases, to highly specialized commercial requirements.

Much of the earlier work of scientific crop improvement in Britain centred on the three cereals, wheat, oats, and barley—a direction of effort that happens to coincide with a ready facility in treatment, for cereals are self-fertilizing and consequently they present none of the complications, amongst them isolation, incidental to cross-fertilizing plants. But there were additional reasons for the choice: one, perhaps, being the perpetuation of the example of men like Patrick Shirreff, the Rev. Dr. John Chevallier, Colonel Le Couteur, and Major Hallett, whose contributions to plant improvement are remembered by the agricultural community with pride and gratitude.

The first steps in the development of scientific plant breeding in this country were taken by Professor Sir Rowland Biffen and his school, whose initial researches in plant breeding had for their immediate object the improvement of the British wheat crop. The direct outcome of this work was the provision of at least two varieties of particular utility to British farmers, but in a wider sense, because of the qualitative and pathological features which Biffen studied, and because such studies were executed in accordance with Mendelian conceptions, it stimulated similar work in all parts of the world.

In order to bring the background of crop improvement

into sharper perspective and to distinguish between the continuance, and possibly the elaboration, of older methods, and the emergence of new ideas and more scientific methods, I will attempt to visualize the position at the middle of last century and compare it with that existing to-day.

In a chapter appropriately entitled 'High Farming', Lord Ernle in *English Farming Past and Present* includes this sentence: 'Pedigree barleys and pedigree wheats were already experimented upon by Patrick Shirreff, Dr. Chevallier, and Colonel Le Couteur.' This is a small but noteworthy tribute to three men who by the introduction of new and improved varieties, and equally by their writings, stimulated a more systematic study of cereals in this country in the nineteenth century.

If for the purpose of studying methods a comparison of achievements be attempted, it is in no way derogatory to Chevallier to describe his contribution as the most fortuitous. It exemplifies, nevertheless, a procedure which was then and is still recognized as fundamental with self-fertilizing plants. The story of the origin of Chevallier barley has often been told, but it will bear repetition:

'About the year 1820 John Andrews, a labourer of Mr. Edward Dove of Ulverston Hall, Debenham, had been threshing barley, and on his return at night complained of his feet being very uneasy, and on taking off his shoes he found in one of them part of a very fine ear of barley—it struck him as being particularly so—and he was careful to have it preserved. He afterwards planted the few grains from it in his garden, and in the following year Dr. and Mr. Charles Chevallier, coming to Andrews' dwelling to inspect some repairs going on (the cottage belonged to the Doctor) saw three or four of the ears growing. He requested they might be kept for him when ripe. The Doctor sowed a small ridge with the produce thus obtained and kept it by itself until he grew sufficient to plant an acre, and from this acre the produce was 11½ coombs (about the year 1825 or 1826). This was again planted and from the increase thus arising he began to dispose of it, and from that time it has been gradually getting into repute. It is now well known in most of the corn markets in the kingdom, and also in many parts of the Continent, America, &c., and is called the Chevallier barley.'

Patrick Shirreff must be included in another class, for although his first introduction, Mungoswells wheat, was the outcome of a chance observation, it encouraged his search for other outstanding forms of wheat, and later of oats. Thus, in the course of time the search became gradually more systematic, and his first success was only the precursor of a long series of valuable varieties, the merits of which were appreciated widely. Finally, Shirreff attempted to produce improved varieties by hybridization, and some of the results he obtained are set out in an account of his work which he was induced to write and publish in 1873—half a century after the introduction of Mungoswells wheat. Shirreff was not, and indeed expressly denied any claim to be, the first person in Britain to have crossed wheat. He was of the opinion that King, the celebrated horticulturist, was perhaps the first; moreover, ears of hybrid wheats were shown at the London International Exhibition in 1851 by two separate individuals—Mr. Maund and Mr. Raynbird.

Some measure of Shirreff's grasp of the basis of crop improvement is afforded by his dictum that 'new varieties of the cereals can usually be obtained from three sources—from crossing, from natural sports, and from foreign countries'. The value of the latter source according to Shirreff was very qualified, for he notes that 'foreign countries have seldom been known to furnish a good new variety of wheat suited to the climate of Britain. . . . The seeds generally germinated well, and the plants withstood the rigours of winter; but in the course of summer, the blossom, the chaff, the grain and the straw generally became so diseased, that none of them was considered worthy of cultivation in East Lothian; but it is probable that my experience at the time may have contributed in some degree to the failure'. This experience is then elaborated by the statement: 'Many of these wheats had come from warm climates; but I have since grown seeds from temperate regions, including California, New Zealand, and parts of Australia. Most of the kinds from the colonies, on reproduction in my experimental plots, appeared to be

identical with varieties in the mother country, and unchanged by soil and climate.' Shirreff concludes his observations on this subject with a remark which might be made with equal force by any one of his successors to-day: 'But many varieties from foreign countries may be found useful in crossing with British.'

To plant-breeders, busy as they are at present in disentangling the mode of inheritance of what, as a working basis, they regard as physiological characters, it is interesting to find that Shirreff, having, as he wrote, satisfied himself of the possibility of changing the seeds and external characteristics of the wheat plant by crossing, resolved to attempt to alter the habit of ripening.

Le Couteur, so far as we are aware, confined his researches to wheat. His contribution to the subject, in addition to several valuable varieties, was a reasoned explanation of the greater agricultural and commercial value of *pure* sorts, and the initiation of comparative tests of yield in the field and in the flour-mill. From his account of his operations one gathers that Le Couteur was unaware of the work of Shirreff, who, it will be remembered, offered his first wheat for sale in 1819, whilst Le Couteur mentions that his attention was first drawn to the impurity of his crops in 1831. Shirreff's recognition of the advantage to be gained by the separate propagation of the produce of single plants is the more remarkable since he did not enjoy the advantage of scientific collaboration such as that to which Le Couteur pays generous tribute in the published account of his work.

Quite accidentally, Le Couteur, who lived in Jersey, came upon a nursery garden in that island in which about eighty distinct sorts of wheat were being grown by Professor Mariana La Gasca, the Curator of the Royal Gardens at Madrid. The interest Le Couteur displayed in the collection evidently aroused a community of interest in the two men, for La Gasca visited Le Couteur's farm on the day following. To his host's dismay, La Gasca drew from a wheat crop he was invited to inspect no less than twenty-three distinct sorts. La Gasca was interested in wheat

from the purely botanical aspect, but not so Le Couteur, who, on reflection, became convinced that differences in the condition of ripeness of the different forms composing his crop must militate against the quality of the flour eventually obtained therefrom, as well as against the yield of grain. In collaboration with La Gasca, he accordingly picked out of his crop fourteen promising sorts which he propagated separately, each original nucleus being an ear or a number of ears of a single plant. The appearance of the produce of these cultures convinced Le Couteur of the value of this method of selection in producing pure stocks; moreover, he was able to claim eventually that the produce of his crops was increased from an average of about 20 to 23 bushels to approximately 34 bushels per acre. Later, with still more careful selection on a yield basis, he obtained 40–50 bushels per acre.

Excepting Shirreff's hybrid wheat, his achievement and that of Le Couteur may be summarized as the isolation and separate propagation of existing forms, and there is no record of either having attempted selection within the produce of individual lines. Shirreff, indeed, appears to have considered this possibility, but rejected it in the following words: 'Many people believe that some plants can be altered by skilful treatment, but my experience has tended to show that there is no way of permanently improving a species but by new varieties.'

But the idea of securing gradual improvements by continued selection in definite directions was widely held about the middle of last century, and in 1861 Hallet published an account of certain experiments of this description he had conducted with wheat. Hallet proceeded on the assumption that 'of the grains in the same ear one is found greatly to excel all the others in vital power'. He found that the plants arising from some grains stooled[1] more abundantly than others and produced larger ears; he therefore proceeded to propagate seed from such ears, and to select from the produce the plants that exhibited a similar superiority in stooling capacity and ear size. The

[1] Stool = ear-bearing stalk.

increased yields claimed for selections made in this way were very substantial, but Hallet's contemporaries expressed considerable doubt regarding the permanency of the advantages; they saw in his method of propagation—each grain being allocated 144 sq. inches—the probable reason for increased tillering and grain size. It is interesting to note that Beaven at a much later date obtained increased tillering in barley by the use of nitrogenous seed, which is frequently a concomitant condition of widely spaced plants.

The position with regard to selection within the produce of self-fertilized plants was not clarified until the appearance of Johannsen's results in 1903. In considering certain aspects of heredity Johannsen came to the following conclusion:

'A breed, a people or a group of any kind—let us call it now or in future a "population"—is, from the biological point of view, not always to be taken as a unit and need not be so taken if for each individual quality an average, presumably typical, value can be found, about which the variations of all the individuals concerned fluctuate in the well-known manner described in the "ideal variation curve" (the curve of the exponential Law of Error). A population of this kind may—as will be shown in this paper—contain several independent types which differ widely one from the other, and which thus need not absolutely show themselves when the empiric curves or tables are observed.'

These far-reaching observations were substantiated by the results of a series of investigations with barleys, beans (*Phaseolus vulgaris*) and peas (*Pisum sativum*), in each of which Johannsen followed the method of inheritance of individual quantitative characters. The whole of his results are too long to give in detail here; in essence, however, they demonstrated that populations consist, as he had postulated, of a number of individual lines each with a mean value of its own for each quantitative character, that the variation around such a mean of any line was normal, and that the selection of extreme *plus* and *minus* values did not affect this mean but exhibited regression towards it. Thus, whilst selection of a population is based

upon a progressive purification, it will cease to be effective when the isolation of the lines exhibiting maximum deviation is complete. In the light of Johannsen's conceptions, the possibilities surrounding Hallet's investigations become more remote unless his original material was heterozygous. On the other hand, Shirreff's and Le Couteur's contributions are thrown into new relief, and as their procedure was based on the recognition and propagation of extreme forms in their 'populations', they effected in practice all that Johannsen demonstrated to be possible.

In modern terms, Johannsen's conclusions may be described as the differentiation of phenotypes and genotypes, that is, of fluctuating values and true heritable values, which when so expressed bring into true perspective the 'progeny test' so long utilized by Vilmorin and Hjalmar Nilsson.

For many years agriculturists in this and other countries have been indebted to the Swedish Plant Breeding Station at Svalöf for valuable varieties of crop plants. The earlier work at Svalöf, which was founded in 1886, was based on the recognition of independent types within populations, and was thus essentially comparable to that of Shirreff and Le Couteur. The Swedish workers, however, elaborated it to such a degree that they were able to demonstrate conclusively that forms, although homogeneous botanically, may still be dissimilar in physiological characters, amongst many others, resistance to low temperature, which play such an important part in determining the economic value of varieties.

The origin of the 'populations' of cereal forms existing, or recently existing, in almost all countries is an interesting subject for speculation, for they bear no closer resemblance to the known wild forms of the species to which they belong than to more modern varieties. In many cases they exhibit considerable ecological value which indicates a lapse of fairly long periods in their evolution, and in other cases possess physiological characters which are apparently of limited utility in the environment in which they are found to-day. In the British Isles the 'land sorts' are less

numerous than in Sweden with its much greater range of latitude and greater extremes of temperature; Archer barley, as it existed in an unselected condition a few years ago, and Rivet wheat are, nevertheless, noteworthy examples of indigenous sorts. But, as Johannsen demonstrated, a limit to improvement in any direction is inevitably reached when the line exhibiting extreme variation in that direction is isolated, for selection within a pure line is ineffective. Thus, in every country, the greater the initial success the more limited became the possibility of further progress in any desired direction, and the gradual adoption of hybridization as a source of improvement was not purely adventure but rather a necessity born of the realization of this fact.

Shirreff was only one of the many early breeders whose efforts in hybridizing were limited in success by the difficulty they encountered in 'fixing' their hybrid products. The accounts of their work left by men like Shirreff are a tribute to their keen observation, and leave one with the impression that only the lack of a numerical expression of the different forms which made up their hybrid progenies failed to furnish them with the key to the riddle of fixity.

Such, in very brief survey, was the very indeterminate position arrived at when Mendel's paper on 'Experiments in Plant Hybridization', first published in 1866, was reprinted in 1901. Mendel's conception of the underlying necessities of studies in hybrid progenies cannot be more concisely stated than in his own words:

> 'Those who survey the work done in this department will arrive at the conviction that among all the numerous experiments made, not one has been carried out to such an extent and in such a way as to make it possible to determine the number of different forms under which the offspring of hybrids appear, or to arrange these forms with certainty according to their separate generations, or definitely to ascertain their statistical relations.'

Mendel's experimental procedure, so clearly forecast in this appreciation, was the numerical determination of the contrasting characters appearing in successive generations

of hybrid progenies. His results led him to visualize a plant as being composed of a number of characters which are inherited independently of each other. On crossing, certain of the characters existing in the one parent appeared in the progeny to the exclusion of the contrasting character as it exists in the other parent; to the former character Mendel applied the term *dominant* and to the latter the term *recessive*. From counts of the numbers of plants exhibiting dominant and recessive characters appearing in the F_2 or second generation of his experimental material, Mendel was able to establish a definite numerical ratio of 3 of the dominant type to 1 of the recessive type. Proceeding to the F_3 or third generation, he found that the recessive types remained unchanged, but that of the dominant types one-third only remained as they had existed in the previous generation, while two-thirds produced dominant and recessive types, again in the ratio of three to one. Thus, the F_2 generation could now be more accurately represented as consisting of plants existing in the numerical ratio of

1 pure dominant : 2 impure dominants : 1 recessive.

Observations of this nature extended to a series of contrasting characters led to the conception now so closely associated with Mendel's name, that, on selfing, a hybrid plant produces an equal number of male and female gametes bearing one or other of any two contrasting characters. As a consequence each gamete has a chance of combining with a like or unlike gamete, thus producing in the case of a pair of contrasting characters the numerical ratio of 1 : 2 : 1.

The number of contrasting characters existing in any two parent plants is large, but this merely implies the extension of the number of possible recombinations of characters. The numerical ratio of forms when 'n = the number of contrasting characters can be stated as follows:

2^n = the number of forms remaining pure
3^n = the number of terms of the combination series
4^n = the number of individuals belonging to the series.'

From the purely breeding point of view the value of this interpretation lies primarily in the numerical definition given to the constant forms obtainable, which, it will be realized, are found in respect of both the dominant and the recessive characters.

The greatly increased attention directed to problems of heredity since the republishing of Mendel's paper is a measure of the sense of order that his exposition conferred on a subject previously so extremely involved owing to the lack of numerical definition. Experimental evidence forthcoming during the past thirty-five years has elaborated some of the earlier acceptations and modified others, whilst there still remains the need for a more exact interpretation of the quantitative and physiological characters with which plant-breeding operations are so intimately concerned. Nevertheless, the fundamental principles enunciated by Mendel are so intimately incorporated in plant-breeding practice to-day that their use is becoming unconscious.

While the huge importations of wheat from the United States and new areas in the process of development in the last quarter of last century was the primary cause of the large reductions in the wheat acreage in these islands, there were others, two of which come within the present review. The development of wheat production in America during the last fifty years is largely centred on one variety, the origin and development of which is one of the romances of cereal history. A Scots farmer named Fife, who had settled in Ontario, procured a small sample of wheat from a friend in Glasgow, who, in turn, drew it from a cargo of wheat landed in that city direct from Danzig. Fife sowed the seed in the following spring, but it proved to be a winter sort and, with the exception of one plant, failed to ripen. Fortunately, that one plant was saved, and its produce carefully preserved and propagated for several seasons. It was found to have a short period of growth and an early ripening habit, both of which features were especially valuable in Canada.[1] Red

[1] An observation recorded by Professor Peter Kalm in his *Travels into North America*, 1748, in addition to its historical interest is a striking

Fife, as the new wheat was named, soon became widely distributed and ultimately replaced the other varieties in general use. In addition to its remarkable agricultural characters, Red Fife proved to be a 'hard' wheat, hardness in this connexion being used to describe a physical appearance of the interior of the grain which, when fractured or cut across, exhibits a dull, steely interior; 'soft' wheats by comparison give a white starchy fracture.

The higher commercial value of true 'hard' wheats as compared with 'soft' wheats is based first on greater ease in milling, whereby the miller is enabled to obtain a higher percentage of flour, and second on the possession of a particularly resilient gluten. To the baker, flour derived from 'hard' wheats is more desirable, for with it he can make a larger, more shapely, and better aerated loaf capable of absorbing and retaining more moisture on baking; an ancillary advantage is less tendency to 'flow', and consequently greater ease in handling in the bakehouse.

A second important influence operating at the time in question was the improvement in milling machinery, such as the introduction of steel rollers and of more efficient screens, which effected a more perfect separation of the finer particles of bran, and consequently ensured a distinct improvement in the colour of the flour. This was by no means an insignificant matter in regard to Red Fife, for it is a red grain variety, and particles of red bran can be more readily detected in the flour of a red wheat than corresponding particles in flour of a white wheat. Indeed, for this reason, Red Fife, when first introduced, suffered under the disadvantages of its colour.

The repercussions of these changes on the British wheat

commentary on the question of earliness in ripening in Canadian wheats: 'Many people have assured me that the summer corn now employed here [Quebec] came from Sweden or Norway, for the French on their arrival found the winters in Canada too severe for the French winter corn, and their summer corn did not always ripen, on account of the shortness of summer. Therefore they began to look upon Canada as little better than a useless country where nobody could live, till they fell upon the expedient of getting their summer corn from the most northern parts of Europe which has succeeded very well.'

grower were serious, for the new wheat possessed greater commercial value in two respects, either of which was sufficient to place the native varieties at a disadvantage.

When Red Fife was grown in England its yield, like that of most spring varieties, was considerably below that of most native autumn-sown varieties, but, unlike that of most 'hard' wheats when grown under English conditions, its 'strength' was maintained.

The economic position arising from this combination of circumstances resulted in an effort on the part of the British and Irish Milling Association to improve British wheat, and fortunately this body found in Professor (now Sir Rowland) Biffen a botanist already interested in the crop, more particularly in regard to the inheritance of resistance to rust (*Puccinia* spp.). Biffen's studies were at once elaborated into a concurrent attempt to secure better milling and baking qualities associated, if possible, with the high grain-yielding capacity of native varieties.

The financial loss sustained by wheat growers as a result of attacks of rust (*Puccinia* spp.) when viewed on a world basis amounts in the aggregate to a very large sum. In Britain, fortunately, the most prevalent species—*P. glumarum*, Yellow Rust—is neither so virulent nor so disastrous in its effect as the species prevalent in other countries; it can, however, on occasions, cause sufficient damage to render any protection against attack highly desirable. Varietal differences in resistance to attacks of *P. glumarum* have been recognized for a long time, and to this fact were due many of the earlier efforts to secure resistant forms by hybridization.

Biffen, in an account of some of his wheat studies, mentions the very high susceptibility of Michigan Bronze to Yellow Rust, and the relative immunity of Rivet. He found that on crossing these two varieties the first generation (F_1) was so severely attacked that he had difficulty in securing viable seed from the few plants he grew.

Other crosses between parents of similar susceptibility and non-susceptibility gave like results, and on carrying the seeds obtained into the second generation the resulting

plants exhibited segregation in the ratio of three susceptible to one non-susceptible, thus confirming the conclusion furnished by the F_1 plants that susceptibility to attack was a dominant character.

With these results as a basis for practical application, Biffen crossed a resistant selection from Russian Ghurka with Squarehead's Master—a native variety, and from the progeny of the cross he derived the wheat now known as Little Joss, a variety which is highly resistant to Yellow Rust and, in addition to a high yielding capacity, is particularly well suited to light soils.

The problem of the qualitative improvement of British wheats was somewhat more involved, for, to meet the necessities of the position, it was necessary to maintain the yield of grain concurrently with any enhancement of quality that might be obtained. In all Biffen's attempts at qualitative improvements Red Fife was utilized as the good-quality parent, and in his earliest crosses, Rough Chaff, a well-known native variety of inferior quality, as the other parent. The first question to be answered was whether the hard, steely appearance indicative of high milling and baking quality existing in Red Fife was a segregating character, and then whether it operated as a dominant or recessive character to the starchy appearance of the 'weak' grain of Rough Chaff and varieties of similar quality.

The evidence obtained from an examination of the grain of the first, second, and third generations demonstrated that the physical character of the grain exemplified by Red Fife was a segregating and a dominant character. As more material from the various cultures became available, these results were corroborated by tests of the resiliency of the gluten. Finally, it was shown that the grain of the 'strong' segregates possessed a higher total nitrogen content than that of the 'weak' segregates, but as the nitrogen content is subject to a large amount of fluctuation according to the fertility of the soil on which a crop is grown, this test could only be utilized comparatively under conditions of soil equality.

One selection of this cross was eventually put into general circulation under the name of Burgoyne's Fife, but, unfortunately, whilst the new variety was a distinct improvement in point of quality, it failed to equal the standard varieties then in use in yielding capacity, and its general adoption could not be recommended.

Biffen followed this attempt with many others, amongst them one in which Red Fife was crossed with Browicks—another native variety then enjoying considerable favour, but, like Rough Chaff, inferior in quality. From this cross he obtained a series of promising segregates, one of which was put on the market under the name of Yeoman. This wheat exhibited a quality comparable to that found in the best grades of 'hard' Canadian or American, and capable of yielding a flour which could be used for bread-making without the admixture of any foreign flour. When tested in the field Yeoman proved to be superior in yield to the native varieties then in use, and even with the lapse of time since its introduction it has maintained its position relative to newer productions when grown on good wheat land; on lighter soils, however, Little Joss can outyield it.

Of the cereals the wheat crop is the one from which an economic response to nitrogenous fertilizers can be most readily obtained without detriment to grain quality or risk of the crop 'lodging'. Since the war, the price of such fertilizers has been very considerably reduced, and the extent to which they can usefully be employed in wheat production has been correspondingly increased. The quantities of fertilizer used must be dependent, however, on the strength of the straw, for increased yield can rarely counterbalance increased harvesting costs consequent on crops becoming 'lodged'.

One aspect of wheat breeding in recent years has been, accordingly, the selection amongst various hybrid progenies in course of development of forms exhibiting straw of superior standing power. Thus Engledow, in the course of developing a variety of enhanced quality from the cross White Fife × Yeoman, has selected a form possessing a straw superior in standing power to Yeoman, and probably

to most other wheats in general use at the moment. The new wheat, Holdfast, is moreover a high-yielding type possessing superior milling and baking qualities.

The problems of improvement in malting barley differ in certain fundamental directions from those just described for wheat. As sufficient barley of malting quality for home requirements is produced in the British Isles, the problems confronting the breeder do not arise from the competition of imported foreign produce, but proceed from what may be described as purely domestic conditions. Arising out of these conditions is the need for better standing straw necessitated by increased fertility of the land devoted to the barley crop and by more mechanized methods of harvesting, the demand on the part of the maltster and brewer for more uniform material, and a growing recognition of differences in the quantitative and qualitative values of the varieties in general use. The combination of high yielding capacity and good quality essential in wheat is equally requisite in barley, but as quality in barley receives a proportionately higher monetary consideration, its claim to attention is relatively greater and more insistent.

Quality in wheat depends to some extent on the quantity, but much more on the quality, of the protein it contains; in barley, on the other hand, quality is mainly determined by the quantity of starch present in the grain, and on the facility with which it can be 'modified' in the malthouse and converted into maltose in the mash-tun.

To those accustomed to dealing with barley its physical appearance is a tolerably safe guide to its behaviour in the different operations it undergoes during conversion into beer. But evaluation on this basis is not invariably correct, and is, indeed, a matter of considerable difficulty when applied to samples exemplifying intermediate values. Beaven, in the course of his investigations on malting quality, found that the total nitrogen content of the grain is a surer guide to malting quality, particularly for differentiating between samples of the same variety or like varieties grown in closely comparable environments.

Thus, grain of superior malting quality is characterized by a low total nitrogen content and, inversely, grain of inferior quality by a high one; these conclusions have been substantially confirmed by numerous malting trials conducted on a scientific basis, and receive wide recognition in practice.

During the last thirty years an extensive co-operative investigation of varietal values has been carried out by the Department of Agriculture in Ireland in collaboration with Messrs. Guinness, the Dublin brewers; these experiments were commenced in 1901 and are still in progress.

The varieties in general cultivation in Ireland at the beginning of the century were Chevallier and Standwell and, to a smaller extent, a 'land sort' indigenous to the country known as 'Old Irish'. The early results of the comparisons established the superior yielding capacity of Archer barley, a 'land sort' grown at that time in the south-east of England, where it had existed, so far as can be ascertained, for a long time in an unselected condition. Fortunately, Archer proved to be very satisfactory malting material also, and the requirements of the two interests involved were adequately provided for in this barley.

The only variety approximating Archer when judged on the combined value of yield and quality was Goldthorpe; the latter, however, showed greater variability in yield from season to season and from soil to soil, but was almost invariably slightly superior in malting quality.

It was evident from the appearance of the crops of all the varieties under comparison in the early years of the investigations that they were not botanically pure, and the next step accordingly was an attempt to purify them, first by mass selection—the selection of a large number of botanically similar ears and the separate cultivation of the seed obtained therefrom, and concurrently, the selection and separate propagation of good single plants, of which one was finally chosen for extended propagation. Both procedures resulted in improvements in yield and quality, but the single-plant selection produced the better results in both respects, combined with a uniformity in growth,

ripening, and size of grain greatly in advance of anything obtained previously.

Although Archer and Goldthorpe were superior to the varieties with which they were compared, they both exhibited defects in the straw of a character which militated against their general acceptance by the farmer. In Archer there was a very decided liability to 'lodge' in seasons of excessive vegetative development, and in Goldthorpe a strong tendency for the ear to become detached from the straw when fully ripe, which was due largely to the long uppermost internode, a considerable portion of which is not enveloped by the sheathing leaf. In marked contrast, the corresponding internode of Archer is much shorter in length and is either completely enveloped by the sheathing leaf, thereby securing additional support, or exposed only for a short portion of its length; the ear in consequence rarely becomes detached from the straw. It thus appeared that if this particular morphological character found in Archer could be combined with the desirable features of yield and quality found in Goldthorpe, the value of the latter variety would be materially enhanced. The two varieties were accordingly crossed, and amongst the progeny resembling Goldthorpe in type of ear and in grain characters a form was found possessing most of the features of the Archer straw. This new barley, later named Archer-Goldthorpe, was found to be equal to Archer in grain-yielding capacity, but, like the parent Goldthorpe, slightly superior to Archer in malting quality; it was, moreover, definitely less liable to the loss of ears so frequently sustained by Goldthorpe.

For some purposes and in certain well-defined environments barleys of the Archer type are preferable to those of the Goldthorpe type. In Ireland, because of its general suitability to the greater part of the area devoted to barley, barleys of the former type were preferred, their only defect being the weakness of straw previously mentioned.

The most desirable straw obtainable in native barleys probably exists in forms classified under *Zeocrithum*, of which Spratt is the most prominent variety still in use.

Spratt has been cultivated in Britain for a very long time; it was widely distributed formerly, but judged by present standards its grain is not attractive, and in the face of the competition of varieties of more pleasing appearance, its use in recent years has become restricted to the Fen districts. There, on soils which produce an over-abundance of straw and crops are frequently severely 'lodged', its strong, upstanding straw is appreciated, and it is capable under Fen conditions of producing prolific yields of grain.

On account of its good straw, Spratt was crossed with Archer, and among the narrow-ear segregates, i.e. ears of Archer type, in the hybrid progeny there were several with distinctly better standing straw than the parent Archer. One of these was chosen for extended propagation and, after careful yield and quality testing, it was finally introduced into general use as Spratt-Archer. Further tests in the field and in the malthouse confirmed the results of the initial smaller scale tests, whilst it was also found that the new barley was slightly earlier in ripening than Archer—a distinct advantage under the comparatively late-ripening Irish conditions—but most important of all, it proved to be characterized by straw of superior standing power.

A few years previous to the time at present referred to, E. S. Beaven commenced a series of breeding investigations which culminated in the introduction of Plumage-Archer barley. From an extended series of comparisons Beaven established the value of Archer barley, and selected a line from this old population which was ultimately circulated for general cultivation. He also determined the value of a variety named Plumage, which was very similar to the Goldthorpe referred to above both in respect of features of value, and of defects. With a barley of the Plumage type but possessing the character of straw found in Archer as his objective, Beaven crossed Archer and Plumage and succeeded in selecting from the hybrid progeny a form fulfilling these requirements which is now widely known and cultivated.

Between the two barleys, Spratt-Archer and Plumage-

Archer, there is no significant difference in yield and quality, but some brewers prefer the type of grain exemplified by the former, and others the latter. Apart from these preferences, there is considerable evidence that Spratt-Archer is more suited to lighter soils in the generality of seasons, and Plumage-Archer to the heavier. But this adaptation depends to some extent on the weather, and cannot be utilized too rigidly; thus, there are seasons in which Spratt-Archer will succeed on the heaviest soils, and others in which Plumage-Archer succeeds on the lightest soils.

In the Irish experiments Archer was used as a standard in all field comparisons, and in the various small-scale chequer-board tests; it was thus possible to compare the earlier varieties which were dropped out and the newer ones which were substituted from time to time, with one standard. If this be done, it is found that compared with Archer the formerly predominant varieties, Chevallier, Standwell, and Old Irish, were inferior in yield by $3\frac{3}{4}$, $8\frac{1}{4}$, and $4\frac{3}{4}$ bushels per acre respectively; Spratt-Archer was superior to Archer by 4 bushels per acre, and the difference between Spratt-Archer and the early predominant varieties may thus be estimated at approximately 1 quarter per acre, which is equivalent to an increase of 20 per cent. on an average field of 5 quarters.

It is difficult, in the absence of actual malting results, to estimate the improvement in quality, but if the total nitrogen figure may be taken as a criterion, then Archer was superior to Chevallier, Standwell, and Old Irish, and slightly inferior to Spratt-Archer.

Finally, there is the monetary value of better standing straw, and straw minus the defects referred to when considering Goldthorpe, and here the difficulty of estimation is the greatest. But one has only to look over a field of Archer to-day, and compare it with adjoining fields of Plumage-Archer and Spratt-Archer, to gain a visual conception of the change that has been brought about in the standing power of the straw, which, it must be remembered, is coexistent with heavier yields of grain.

When considering the improvement of cereals we see

some features, such as yield and quality of grain and standing power of the straw, which are common to wheat, oats, and barley. In the oat crop, however, the question is further involved by considerations of the feeding-value of the straw, and resistance to certain insect attacks, particularly Frit fly. These may all be classed as primary considerations, but since the oat crop is much more widely distributed geographically than wheat and barley, other features, such as relative earliness in ripening and adaptability to definite environments, cannot be overlooked.

The early agricultural writers classified oats on the basis of the colour of the grain only; they were thus either white, black, or red. The one exception was the small-grain, naked oat, which is still grown in a few isolated districts as Piley or Pilcorn (literally 'Peel' corn, by reason of the naked condition of the kernel). With the arrival of Sandy and Potato in Scotland, and, somewhat later, of Poland in England followed by Shirreff's selections, oats began to be regarded under more rigid definitions.

In 1892, Gartons introduced their first hybrid oat, Abundance, which in almost all respects was a milestone in oat improvement. A long series of hybrid varieties, produced by the same firm and by others, followed in rapid succession, but none of them met with the sustained success of Abundance. In 1908, the Svalöf Seed Station introduced Victory, which deserves notice alike for its origin and its merits. This variety was obtained by single plant selection from Milton oat, a type of the Probsteier 'land' oat, which also yielded Golden Rain. Between Abundance and Victory differences of yield are not very marked, but the latter is characterized by a wider range of adaptability, and by a finer straw.

The list of varieties produced by seedsmen has been augmented in recent years by the products of Plant Breeding Stations. Thus, in the Irish Free State, Fluirse, Glasnevin Success, and Sonas, all characterized by good straw and large grain, have been put into circulation and found particularly well suited to the environment in which they were produced by Caffrey; similarly, Stormont

Arrow, Iris, and Kern, produced by Seaton, have been found very valuable in Northern Ireland, and Early Miller, Elder, and Bell, Robb's productions, in Scotland; in Wales, in addition to winter sorts with good straw, Jones has produced forms of *Avena strigosa*, the species tolerant of soil and rainfall conditions inimical to forms of the ordinary species *A. sativa*, which exhibit improvements in the quantity of both straw and grain.

The market value of oats is commonly determined by the size of the grain, but this is not necessarily a criterion of intrinsic feeding-value, for this depends on the quantity of husk investing the true grain, and the quantity of husk is independent of the size of the grain. The oat grain divested of husk is similar in composition to wheat except that it contains a higher percentage of crude oil and a lower percentage of fibre. The husk, which may contribute anything from 20 to 35 or even in some extreme cases 40 per cent. of the total weight of the grain, is composed of approximately one-third of its weight of indigestible fibre lignified to an extent that renders it useless as a food, whatever its physical value in the process of mastication may be. It is, consequently, this portion of the grain that actually decides the feeding-value, and it is for this reason that, in most attempts at improvement, a low percentage of husk is regarded as a desideratum.

If the various introductions of the last fifty years are compared with the varieties existing previously, two striking changes are apparent—the first from varieties of high straw and relatively low grain yield to varieties of lower straw and relatively high grain yield, and the second from small grain with low husk to larger grain with higher husk content.

The oat is a plant requiring abundance of water during the period of active vegetative development. In some districts this is provided naturally by an ample rainfall, and in regions of lower rainfall it is countered by sowing early in the year, thereby encouraging a large and deep root development before the effect of any moisture deficiency is felt. This procedure, however, necessitates

favourable weather, and when for any reason sowing is delayed, and conditions of insufficient moisture supervene immediately afterwards, development is seriously restricted, and the plants become very dwarfed. The prolongation of dry conditions into the month of May reduces the crop to a condition of easy attack to the Frit fly, the first swarm of which becomes active during that month. The Frit lays its eggs on the leaves of the oat plants, and the larva makes its way to the growing point by either burrowing directly or by travelling to it between the leaf sheaths. Having reached the growing point the larva feeds on it, thereby rendering further development impossible. A proliferation of tillering is thus brought about, but none of the late-formed new shoots attains the size of the original main shoots; in severe attacks the plant may fail to produce any ear-bearing shoots, while even mild attacks readily bring about losses estimated at from 25 to 50 per cent. of the crop.

Fortunately, Frit attack has been found amenable to treatment on a varietal basis, for several of the Scandinavian 'land' oats exhibit varying degrees of resistance to the pest. Cunliffe has demonstrated that when these particular varieties are crossed with the more commonly cultivated but less resistant varieties, resistance and susceptibility segregate, and that up to the present there is no evidence of linkage with characters which would render the new resistant forms less valuable economically. Thus, by crossing Spete, a Swedish 'land' oat, with Star, Cunliffe has succeeded in obtaining a variety which affords a large measure of protection. The actual degree of resistance in this as in analogous cases is subject to fairly wide fluctuations attributable in part to the incidence of attack in relation to the stage of development of the plant at that time, and in part to the number of flies concerned in the attack. Despite these conditions, the new resistant varieties have exhibited consistently less damage than the non-resistant, and furnish the first, and that a most encouraging example of the co-operative effort of plant breeding and entomology in this country.

A more indirect but very effective defence against Frit fly is afforded by the use of winter oats. It appears that the extent of damage is determined, to a large extent, by the ease with which the fly can reach the growing point of the shoot, and this is qualified by the stage of development of the shoot at the time of attack—usually in May. Oats sown in the autumn are less vulnerable to attack by reason of their more advanced condition at that date, and they are less affected by early summer drought—a not infrequent feature of the climate of the Eastern Counties.

But the use of oats for autumn sowing implies the provision of winter-hardy varieties, of which the number available is very limited; moreover, they are characterized by long, fine straw, of excellent feeding-quality but notoriously liable to 'lodge' on any but the thinnest soils. They do, however, produce grain of the highest feeding-value. The breeding problem is thus resolved into the production of varieties resistant to low temperatures and other conditions which together make up the winter conditions met with in this country, with improved standing power in the straw, combined with high grain-yielding capacity. These things being equal, then grain with a high feeding value, i.e. with a low husk content, would be preferred.

The problem has been attacked at Aberystwyth and Cambridge, and at both places Grey Winter has been utilized as the winter-hardy parent, whilst Kyko at Aberystwyth and Argentine at Cambridge have been used as parents exhibiting superior straw characters; the latter are spring varieties, and their use was necessitated by the lack of true winter forms possessing the requisite strength of straw.

The determination of winter-hardiness in the hybrid progeny, which was the primary necessity, is always difficult in a temperate climate where the incidence of severe winters is extremely irregular, and in the absence of any artificially controlled low-temperature apparatus; but the evidence obtained in the severe winter of 1928–9 was valuable. This, by the courtesy of the Svalöf Plant

Breeding Station, was implemented by tests carried out under artificially controlled conditions, and in the open at Svalöf. Resistance to low temperatures in the various segregates under review did not appear to be due to one factor difference, for there was a gradation in value between the winter-hardy parent on the one hand and the spring parent on the other. But at both Aberystwyth and Cambridge forms were ultimately selected which exhibited a degree of resistance to winter conditions approximating to that of Grey Winter, and with straw characters decidedly superior to those of that parent; in both, the yield of grain also was decidedly superior to that of Grey Winter.

The percentage of husk in the hybrid progenies showed a series of values equal to the parents in a few, but more generally intermediate between the two, and these latter could be stabilized by single plant selection within families. Thus, since the percentage of husk segregates, it can be treated as a definite breeding objective, but the degree of association, if any, between high and low husk content and good standing straw still requires determination.

More recently, further derivatives of the cross, Grey Winter × Argentine, have been isolated which possess a degree of winter-hardiness at least equal to Grey Winter, and the possibilities of progress in this direction have thereby been substantially advanced.

In many essential respects the problems surrounding self-fertilizing plants, of which the cereals may be taken as representative, are the most readily amenable to treatment. Yet to some, the results obtained even with this class of plants in the past thirty years, justified as they may be in an economic sense, do not fulfil the enthusiastic expectations engendered by the appearance of Mendel's historic paper.

This partial failure to synthesize plants according to preconceived plan arises to a large extent from conditions which have been more accurately defined, as the result of much more extensive investigations than Mendel, single-handed, could have undertaken. It is now recognized, for instance, that plant attributes such as length of

straw, resistance to disease, earliness in ripening, and many others which together form the basis on which economic values in crop plants depend, cannot be regarded as unit characters in the sense first conceived. We are obliged, indeed, to conclude from experimental evidence that many plant characters are extraordinarily complex in genetic constitution, as is also the interaction between the complexes constituting respective plant characters. Moreover, every hereditary complex is greatly modified by the environment in which it operates. The number of combinations possible on crossing two varieties, consequently, is extremely large, and the number of individual plants requiring evaluation alarmingly increased. There are certain conditions, fortunately, which retrieve what would otherwise threaten to become a chaotic position: the number of genes operative for any character are not invariably additive in effect, or at least their effect is so small as to be undetectable by existing methods of measurement. In such cases the expression of a character for any given environment may be static, or at least it behaves as in a state of equilibrium in relation to any definite environment. But a condition of this nature connotes the possibility of change with any large difference in the environment of the plant; it likewise invokes an expectancy of instability which treatment on Mendelian lines was expected to obviate.

A further complication arises out of the difficulty in recognizing the expression of such important attributes as yield of grain, which cannot be regarded as a single character in the Mendelian sense, but rather the end result of several characters, all of which, moreover, are subject to wide fluctuation in expression. In this connexion the efforts of Engledow and his colleagues to separate yield of grain, as an end result, into its component parts have been an important and helpful contribution. The fundamental result of such studies has been to demonstrate the relation of grain yield in British cereals primarily to high tillering capacity and high rates of ear survival. This at least focuses attention on two plant characters,

and furnishes a basis of selection which may be applied with some degree of confidence to the individual members of early hybrid progenies. At the same time, it may be noted that Frankel, as the result of similar studies in New Zealand, emphasizes the value of a fairly large ear, and of smaller numbers of ear-bearing shoots in the most prominent wheats used in that country. This confirms that it is incorrect to regard yield as a definite character in the Mendelian sense; rather is it attributable to a series of quite distinct characters, all of which are liable to differ in importance according to the environment in which they exist. Similarly, it is difficult to consider quality in wheat, barley, or oats without relation to the influences of high tillering and other allied plant characters.

Finally, just as one plant attribute may be primarily important in relation to a definite feature in one country, whereas another is of relatively greater importance in another, so it is with varieties under any one set of conditions.

For reasons such as these, the application of scientific results obtained outside the immediate problem of the plant breeder is difficult, and it is not easy to visualize conditions in which it can be otherwise. Once having passed beyond the range of botanical and morphological differentiation of hybrid progenies, the breeder is faced with the necessity of making decisions on material which can only be evaluated with the assistance of a previously conceived standard of fluctuation, and a trained mental appreciation of the diversified manners in which yield and quality may be expressed.

Flax, by reason of its long and uninterrupted association with the human race, is entitled to be regarded with wheat and barley as one of the collateral agents of civilization. How and when flax reached Britain is uncertain; by some authorities its introduction is attributed to the Phoenicians, while others accredit its appearance to the Egyptians. There is no doubt, however, that it was cultivated very generally in England from an early date, and the incorporation of the word 'flax' in the names of villages

throughout the country testifies to a close association of the plant with the social life of our forefathers. It is interesting to note also that statutes were enacted in the sixteenth century requiring a proportion of all arable land to be sown with flax or hemp.

The various processes entailed in the production of linen from the flax plant have never been readily amenable to labour-saving devices, and in early times the whole of the operations from growing to weaving the final fabric were performed by the farmer and the members of his household. Thus, with the advent of cotton fabrics manufactured more cheaply by the use of highly mechanized operations, the general use of linen was greatly reduced, and except in a few isolated spots the crop ceased to be cultivated in England. In Northern Ireland, on the other hand, where the climate favours the crop and is particularly suited to bleaching the manufactured fabric, flax still occupies an important position.

Prior to the Great War, practically the whole of the seed-supply of Northern Ireland was drawn from Russia, directly or through Holland, which, in turn, derived its supply from Russia. During and after the War this supply was seriously interfered with, and the position of considerable difficulty thus occasioned had to be met by the production of seed in Ireland or elsewhere under supervision. With most crops the production of seed presents no special difficulty, but the best-quality fibre is not obtained from crops which are allowed to grow until the seed is ripe; on the other hand the best seed is only procurable from fully ripened plants. Consequently, although the fibre derived from plants grown for seed is not entirely valueless, seed crops must in the main be regarded as meeting that one requirement only.

For many years before the Great War the Department of Agriculture in Ireland had carried out series of experiments directed mainly to the determination of the most efficient manurial treatment of the crop, and of the effect of those treatments on the quantity and quality of the fibre produced.

But, largely owing to the insistence of a flax-grower named J. W. Stewart, efforts at improvement gradually assumed another direction. Stewart, like other observers, began to recognize the very mixed condition of the flax crop; he realized that there were differences in the height of the plants, in the extent to which the inflorescence was branched, and in the time of maturation. Now the whole value of the crop depends on the quantity and quality of the fibre that can be abstracted therefrom, and this is determined by the length of the plant, the number of the fibre bundles contained in the stem, and finally on the *lumen*, or empty space, occurring in each fibre. Extreme branching is undesirable, as it is usually associated with reduced length of the plant, and the fibre of the branches, which becomes detached from that of the main stem during scutching, is too short to be utilized economically in the production of the best linen fabric. In 1910 the Department of Agriculture initiated a series of investigations which had for their object the production of improved strains of flax, and the first line of inquiry was the extent to which the plant was or was not self-fertilizing. These initial inquiries demonstrated that the flax plant is almost entirely self-fertilizing, and the investigations then followed a line similar to that of the early wheat and oat breeders, namely, single-plant selection and evaluation.

The first selections, Nos. 3 and 5, were made from crops of Pernau Crown flax, and were characterized by an evenness of growth greatly in advance of that of crops derived from the ordinary commercial seed.

Shortly after the War the Linen Research Association of Northern Ireland developed a pure strain of flax which was named 'J.W.S.' as a small recognition of the earlier pioneer work of Mr. J. W. Stewart. This selection proved to be a distinct advance in all respects on the commercial seed then available, and its adoption by the farmers in Northern Ireland marks a noteworthy advance in the improvement of the crop.

In later years 'J.W.S.' has been largely superseded by other selections, such as Stormont Cirrus and Stormont

Gossamer, made by Megaw out of a crop grown from Russian seed and developed by the Ministry of Agriculture for Northern Ireland, and Liral Crown, Liral Monarch, and Liral Dominion, produced by the Linen Research Association.

Some of the more recent selections exhibit superiority to 'J.W.S.' in less liability to lodging, others in earlier maturity, and others in a higher percentage yield of fibre. They thus provide a wider basis of selection for the farmer for his particular environment, and according to carefully conducted tests they yield a monetary return no less than 50 per cent. in advance of that of commercial seed formerly in use.

It is evident to all students of agricultural economy that the future of agriculture in this country is intimately concerned with live stock and live-stock products, and that amongst the various objectives of crop improvement the forage crops naturally assume a pre-eminent position. Forage crops, in so far as they consist of grasses and clovers, are most readily and economically produced in regions of ample rainfall, and consequently are found in the highest ratio to arable crops in the western districts, just as the condition of lower rainfall leads to a similar concentration of cereals in the eastern districts.

The value of a forage grass, whether utilized for hay or pasture, depends largely on the quantity of edible material obtained from it in either of these two forms. Hay and grass are, of course, end products, but highly important considerations in the evaluation of species and strains of species are such features as permanency, the rate of development in the early months of the year, the quantity of aftermath, and, finally, the aggressiveness of the species, that is its ability to maintain itself in the face of the competition of other species.

While the value of a cereal is largely determined by the quantitative development of the essential portions of the inflorescence, that of the grasses is centred on the vegetative rather than the reproductive organs of the plant. The development of the seeds contained in the

inflorescence proceeds *pari passu* with a loss in nutritive value in the straw and leaves of cereals and grasses alike; thus the objective in the production of hay is to secure maximum vegetative development in a quantitative sense, without prejudicing the value of the hay qualitatively. The optimum time for cutting hay is consequently at or just after the plant has flowered and, hence, before the transference of material from the stem and the leaves to the seed has gone far.

Of the various parts of the stem the leaves are the most valuable nutritionally, and amongst these the order of value decreases regularly from the uppermost or youngest to the lowest or oldest. Frequently, however, new tillers appear at the base of the plant at an advanced stage in the age of the main stem, and these being mainly young tissue are the most nutritious of all parts of the plant at that stage.

Stapledon and his colleagues at Aberystwyth, by whom the study of grasses and clovers has been so materially advanced, have shown that the variations in the 'populations' of the different species of grasses as at present existing comprise differences, amongst other things, in the number of seed-producing stems per plant, and in the ability of the plant to produce leafy shoots which exhibit no tendency to develop into flower-bearing stems; such plants, by reason of the high nutritive value of younger as opposed to older tissue, are more valuable for feeding. Plants of perennial rye-grass obtained from old-established pastures, and on that account termed 'indigenous', have been shown to out-yield crops derived from ordinary commercial seed by 13 per cent. when judged on two years' results, whilst at the end of that period the 'indigenous' was also found to exceed the 'non-indigenous' in tiller production by 50 per cent., and at the same time exhibited a higher degree of permanence.

Proceeding from considerations such as the above, the early investigations at Aberystwyth were directed to a study of the forms of various species in relation to their respective habitats, and following this, to the selection of

individual plants exhibiting the particular features required for definite purposes.

Up to this point there is a similarity in the breeding procedure adopted for cereals and grasses, but the lines now diverge, for while the cereals—wheat, oats, and barley—are self-fertilizing, the grasses are in part self-fertile but more generally largely self-infertile, and not infrequently self-sterile. These conditions are further complicated in the following way: first, that in some, continued selfing leads to a progressive loss of vigour; secondly, that there exists a certain degree of both compatability and incompatability between strains and lines of the same species; and finally, that in the choice of individual segregates from crosses there is a tendency, in picking the most vigorous plants, automatically to select the heterozygous and therefore the less stable forms. In view of these conditions the breeding procedure is resolved, first, into the determination of the value of parent stocks apart from the benefit of hybrid vigour, that is, when selfed, and, secondly, their value when crossed with other parents treated similarly. The time and labour involved in a programme of this nature can readily be appreciated.

During the course of the search involved in these investigations self-fertile forms have been isolated, and if these prove to be sufficiently vigorous and to maintain their vigour, the breeding problem may be greatly simplified. Up to the present, the number of such forms that have been isolated is not large, and a longer series will be necessary to meet all environmental and economic conditions involved. Nevertheless, their existence is a fact of some consequence, and their inclusion in the general scheme of inquiry may ultimately further the objects of the whole investigation.

Where a selected plant is self-fertile, even if only to a limited extent, and is in other respects desirable, the process of multiplication is facilitated by detaching the tillers from the parent plant and planting at regularly spaced intervals—a procedure which may on occasions be usefully employed with cereals. But frequently the combination

of two or more strains is essential in building up the desired type, and one or more of them may be self-sterile, when its value can only be established from observations made on material that has been propagated vegetatively.

Despite the complicated nature of these breeding operations, new strains have gradually been evolved at Aberystwyth, and are now being absorbed into farming practice, where, under varied conditions of treatment, both their quantitative and qualitative values will be amply determined. The wide differences of soil and climate under which they will be grown, and the various treatments to which they will be subjected, make it unlikely that the new strains will be equally successful in all areas, and it would be idle to expect such general adaptability. But there is ample justification for the prosecution of further inquiry, and the very welcome promotion of a new mental evaluation of grassland, from both quantitative and qualitative points of view.

Amongst crop plants the potato may be regarded as the most valuable contribution of the New to the Old World. As an almost universal source of human food the potato has occupied an unassailable position, especially amongst the European and North American peoples. On occasions, however, it has suffered from disastrous crop failures, which have been attended with far-reaching social and political consequences. The Irish potato famine, for instance, resulting from a severe epidemic attack of 'blight' (*Phytophthora infestans*) in 1845 and 1846, caused an unprecedented emigration of the Irish rural population, which fell from 7 millions in 1841 to approximately 4¾ in 1861, as a direct outcome of that visitation.

The position of potato production succeeding the disaster was precarious, and was not improved by the negative results of attempts to find resistance to the then new disease amongst the domestic varieties in common use.

In time, however, new varieties such as Champion, Sutton's Flourball, and Magnum Bonum made their appearance, and for a time displayed some resistance, but

this disappeared completely after a few years in general cultivation.

The position with regard to the resistance to 'blight' has been found, in recent years, to be complicated by the presence in the plant of plant maladies now known under the general denomination of 'Virus diseases'. Salaman has shown that potato 'blight' does not make headway on plants grown in the open which, at the time of initial attack by the disease, are not well advanced towards their maximum stage of growth. The presence of virus affects the normal development of the plant in several ways, and amongst others promotes a tendency to earlier maturity. Thus, by hastening maturity, virus may bring the plant within range of the limit of the activity of the fungus, and consequently be a contributory factor to the loss of resistance to *Phytophthora*. It is interesting to note that Davidson, working in the Irish Free State, has been able by careful selection and cultivation under controlled conditions to develop a stock of virus-free Champion potato, and that this stock exhibited more resistance to 'blight' than stocks of the same variety which had not been subjected to an identical process of selection.

New and economically valuable varieties, amongst which McKelvie's Arran series are notable, have been produced in the last thirty years. The practice of spraying the crop with various copper compounds used in both the wet and dry state before the appearance of the disease has proved an effective means of control, but not without adding to the cost of production of the crop. The most effective control, namely resistant varieties, has proved an elusive problem, and with reluctance it must be admitted that genetic resistance to *Phytophthora* is absent in our domestic material as it exists to-day. Consequently, if resistance is to be utilized, it must be searched for in species other than *Solanum tuberosum* from which the present-day potato as we know it was evolved.

In 1908, in the course of the search directed to this end, Salaman discovered resistance in selfed seedlings of *S. edinense* which was wholly independent of the stage of

maturity of the plants. This material provided tabulum for hybridizations, and a number of new forms were obtained, but all, unfortunately, succumbed to 'blight' in the open.

A more hopeful advance was made in 1914 arising out of Salaman's observations that *S. demissum* (*S. utile*) exhibited outstanding resistance. Some of the hybrids derived from crosses of this species with domestic varieties, and subsequently back-crossed and selfed, exhibited good economic characters combined with the desired resistance, but again failure appeared inevitable when, in 1932, the new 'resistant' potatoes succumbed to attack in the field—a result which coincided with those obtained by Müller in Germany with similar crosses.

The position was clarified shortly after this by the discovery by Miss O'Connor, one of Salaman's assistants, of a biotype of *Phytophthora infestans*, which has since been isolated in single-spore cultures by Petterson. This important discovery was confirmed by the finding, in Germany, of a similar biotype, and further researches along the same lines have extended the number of these new forms of the disease. The establishment of the existence of biotypes of *Phytophthora*, disturbing as it may be for the breeder, did at least afford an interpretation for results which had previously been perplexing.

The possibilities of reaching a solution to the problem have fortunately been advanced another stage in the last two or three years by a further discovery by Miss O'Connor of resistance both to the common and to the newly discovered forms of *Phytophthora* in a South American species; still more recently it has been found that certain types of *S. demissum* and allied types, from Mexico, possess a like resistance.

As a result of this new information it will be possible to proceed with actual breeding operations with a greater degree of confidence. The whole story furnishes an excellent example of the complexity and ramifications of problems attending one aspect of potato improvement, but it is only complete when viewed in conjunction with virus

diseases peculiar to the plant. It also emphasizes the necessity of fundamental mycological studies before the plant-breeder can operate with any legitimate hope of ultimate and permanent success.

The range of plant-breeding activities to-day is wide, and in a brief survey such as the present, confined though it is to agricultural crop plants, it is impossible to include an account of all activities. It is hoped, nevertheless, that those which have been presented will be regarded as representative; where they have been treated in some detail the object has been to illustrate the greater complexity of the breeder's problems when agricultural and specialized commercial requirements demand collateral treatment.

Very natural questions arising from even substantial successes are concerned with the permanence of the improvements that have been effected, and the possibility of adding to what has already been achieved.

When reflecting on the large number of varieties of hybrid origin, which at the present juncture furnish the main material of progress, it is difficult to escape the conclusion that many of these come and go with bewildering rapidity. For reasons already outlined, the potato is somewhat exceptional, but the issue is distinctly joined in cereals, which, being self-fertilizing, should be found capable of maintaining a high degree of stability. Some new productions fail to exceed established varieties in the combination of attributes which determines agricultural value; in this connexion a body such as the National Institute of Agricultural Botany performs a most useful and necessary function by obtaining and circulating to the community the results of carefully devised comparisons carried out under normal field conditions. But even in well-established varieties of hybrid origin evidence is gradually accumulating that the exercise of the utmost care in the initial selection does not preclude the possibility of both quantitative and qualitative changes after the lapse of varying periods of time. The determination of the extent to which these changes are detrimental is a matter

of some difficulty, and it is clear that the subject must be viewed in relation to the particular crop affected. Small changes in oats, for instance, might not justify the long and elaborate procedure necessary to re-establish the original, which similar changes in barley, where quality is important, and to a less extent in wheat, would justify.

The ultimate origin of the changes is still a matter of conjecture, but as they have not been observed in pure, old-established varieties, it is probable that they arise from the hybrid character of those varieties in which they appear. Their possible appearance, however, enjoins on the breeder the need for continual watchfulness and, when necessity arises, of re-selection.

As to the possibilities of further development, a forecast must necessarily be speculative. However, there are records available now, as there were not fifty years ago, to show what has been done and how it was accomplished; these, reinforced with the results of genetical and cytological research which have delimited the possible from the impossible, remove it from the realms of prophecy. Plant improvement, up to the present, has been exercised on material already to hand in the shape of numerous natural 'populations' of ecological types, and in so far as superior constituent forms of these populations have been selected and the inferior rejected, the ultimate aim of the selectionist has been achieved. Following this, and to a large extent because of the finality attached to the success of the earlier procedure, came the period of hybridization of forms which were in the main nearly allied, that is, they belonged at least to the same species. At stations such as Svalöf, which has been in operation for more than fifty years, the breeding procedure for cereals has been the gradual accumulation of small improvements, each progressive step being utilized to secure the next, but at no time have species other than the original been used.

As an example, commencing with the old English Squarehead wheat which was not winter-hardy in Sweden, and native Scandinavian varieties which were winter-

hardy but otherwise not very desirable, the Svalöf breeders have produced a series of varieties of progressively enhanced value, suitable to the winter conditions of their own country, and yet of considerably greater yielding capacity than both of the original parents. A similar procedure with oats and barley has resulted in equally valuable products, and there is, moreover, no evidence at present that this scheme of breeding is reaching finality through any defects inherent in the system.

Despite the success of breeding operations such as the above, there are occasions on which it is necessary to resort to species crosses in order to obtain the benefit of some one or more highly developed characters; an example is provided by the hybrid *T. persicum*× *T. vulgare* in order to utilize the resistance to mildew (*Erysiphe*) possessed by the former. A still more striking example is that of Hope wheat, produced by McFadden in U.S.A. by crossing Yaroslav Emmer, a form of *T. dicoccum* highly resistant to Stem and Leaf rusts, with Marquis, a well-known form of *T. vulgare*.

The recent species crosses of potato mentioned above are another example of the utilization characters not present to the requisite degree in the normally cultivated species.

In Russia, extremely interesting results have been obtained from crosses of distinct genera, as for instance, those of rye (*Secale*) with wheat (*Triticum*), the objective in this case being greater winter-hardiness, which would enable the existing Northern limit of cultivation to be extended. From these crosses stable forms have been obtained with many of the grain characters of rye associated with a winter-hardiness in excess of that possessed by the rye parent; the baking quality of the grain is also claimed to be superior to that of rye.

Thus, in effect, while substantial improvements have been obtained by utilizing existing plant material possessing a high degree of adaptation to the environment in which it is found, the necessity and the value of extending the basis on which parental material is chosen is not

precluded. Nevertheless, such an extension entails the necessity of selection over a wider range of progeny, frequently attended with increased difficulty in securing forms which conform with established commercial standards.

During the last few years cytological and genetical researches have been directed to an increasing extent to the production of artificial polyploids. It has been shown that where the chromosome number of a plant is increased, an attendant phenomenon is an increase in the size of its various organs. This may, it is thought, signify a similar enhancement of plant characters of peculiar interest economically. Sometimes a doubling of the chromosome number has been effected by the use of heat, and sometimes by the application of low temperatures at the time of gametogenesis; sufficient evidence of the value of the resulting new plants, however, is not yet forthcoming.

Amphidiploids have also been obtained in certain species crosses, such as radish and kale, but owing to imperfect pairing of the chromosomes the resulting progeny exhibits varying degrees of infertility. Recently it has been found that the alkaloid colchicine applied to the growing point of young stems inhibits the formation of the spindle threads on somatic division, and in this way brings about a doubling of the chromosome number. The process is only in the earliest stages of experimentation, but its value in conjunction with amphidiploid material, and especially in relation to the development of crops the economic value of which depends upon the bulk of vegetative matter they can produce, is likely to be very considerable.

Finally, the value of hybrid vigour in crop plants such as the grasses, clovers, sugar-beets, and others is too well established to require emphasis. Hybrid vigour is, nevertheless, one of the most intangible problems facing the plant breeder to-day, but its importance must justify attempts to elucidate its origin and so to bring the phenomenon under a greater measure of control.

OUTLINES OF THE HISTORY OF PLANT VIRUS RESEARCH

By Redcliffe N. Salaman

PLANT virus research is one of the most recent additions to science in this country, but its growth has been rapid. The existence of pathogenic agents, so small as to be invisible by ordinary microscopic methods and not retained by fine porcelain filters, was first made known by Iwanowski (Russia), in 1893, as a result of his observations on the mosaic of tobacco. Adolph Mayer (Holland) had shown, in 1886, that this disease was sap-inoculable and that neither bacteria nor fungi were to be found therein. Iwanowski's work remained unnoticed, and it was not till Beijerinck (Holland), in 1898, repeated the experiments and put forward the theory of a non-particulate pathogen, a 'contagium vivum fluidum', that the new views attracted notice amongst pathologists.

Beijerinck suggested that the disease peach-yellows, which Erwin Smith (U.S.A.) had described in 1905 and shown to be communicable by graft, was another example of the same type of infection, and thus helped open the door to fields of research undreamt of in extent and complexity.

So far the curtain had been rung up and the stage held by the plant pathologists. It was not long before the animal pathologists played their role. In 1898, Löffler and Frosch (Germany) proved that foot-and-mouth disease was due to a virus infection. The work of Prowazek (Germany), 1905, placed small-pox, and that of Landsteiner (Germany), 1909, acute anterior poliomyelitis, in the same group; in quick succession an increasing number of affections of both man and animal were shown to be due to similar agents. Indeed, this field, in which the first furrows had been ploughed by the botanist, was, for the next decade and a half, almost entirely occupied by his colleagues of the medical and veterinary professions. An exception, however, should be noted: in 1906 the plant geneticist Baur (Germany), working on *Abutilon*, proved

that the variegated form, introduced into Europe some forty years previously and regarded as a natural variant, owed its characteristic appearance to an infectious agent which could be transferred by grafting to the normal green plant, inducing a like variegation. This discovery suggested that variegations in other plants might be of the same nature. Clusius, in 1576, had described such in tulips, and Daniel Rabel illustrated 'broken' tulips, as they are called, in the *Theatrum Florae* published in 1622.

Miss Cayley (Merton), in 1928, and McKenney Hughes (Merton), in 1930, working at the instigation of Hall, proved, the one that it was a virus infection that could be communicated by sap, the other that the common aphis, *Myzus persicae*, was the vector in nature.

Although virus research proper is of recent origin, yet our forefathers contributed a wealth of literature on certain plant diseases which troubled them and which are known to-day to be due to virus infections. Both observation and discussion were focused, in the main, on the potato and its troubles; as a result, questions which were really pathological in character were considered to some extent from a social and economic standpoint. The potato trouble was spoken of as the 'curl': under this name several diseases, which we now know to be caused by viruses, were included. Some have regarded the term as referring exclusively to leaf roll, but this is surely an error, for we meet with descriptions of the curled potato in which the leaves are compared to a savoy cabbage, an appearance common to a chronic infection with the 'Y' virus. In England, the history of 'curl' can be traced for over 150 years.

In some districts it reached at times an acute stage, bringing in its train crises amongst farmers in the north of England, who had accepted the potato as one of their chief crops. It was on one such occasion that the Manchester Agricultural Society, in 1778, offered a prize for the best method of dealing with the scourge. Thirteen essays were submitted: one learns that the disease had been recognized for about a dozen years; that tubers of

diseased plants conveyed the disease to the next crop, and that varieties differed in their susceptibility. One essayist finds coloured potatoes, especially those with colour inside, less susceptible, an observation that is well worth bearing in mind.[1] Several record that 'seed' off the fen or moorlands of Lancashire is more free from the disease, but should seed from curled plants be taken to the moor, the stock remains curled. Finally, one regarded the whole trouble as being due to the green-fly! The Society did not think this suggestion worthy of recognition, and no prizes were awarded—a striking example of a discovery being made before public opinion was ready to accept it.

Much might be written, did space allow, of the interest which such scientists as John Anderson, 1795, Thomas Andrew Knight, 1818–33, and W. Aitken, 1837, in England, Putsche, 1819, in Germany, and Aimé Girard, 1891, in France, took in the problems of potato curl. Of the polemics which raged as to whether the trouble was due to old age, a physiological failing in the variety itself, or to soil and climatic conditions, one cannot speak here.

In 1913, a new era of active research began and the plant pathologist once more came to the fore. The workers were American and Dutch who, though few in number, yet created between 1913 and 1920 a definite epoch in the history of our subject. Allard (U.S.A.) in his work on tobacco mosaic, 1914–18, first realized the importance of studying the physical properties of the infective agent; he further demonstrated the systemic distribution of the virus in the affected plant, and the infectivity of the sap throughout the plant as shown by inoculating it to healthy plants. Although his actual data were vitiated by an intercurrent infection of his plants, Allard was the first to demonstrate the fact that insects can act as vectors of a plant virus disease. Unfortunately, he thought he was experimenting with tobacco mosaic virus, whereas he was probably dealing with that of cucumber mosaic.

[1] For the writer's views on this and related problems, see *The Indian Journal of Agricultural Science*, vol. viii, pt. ii, April 1938.

Orton (U.S.A.), 1914, was the first to recognize mosaic of the potato as a clinical entity; he had observed it in Germany, in 1911, and differentiated it from leaf roll. He was of opinion that neither bacteria nor fungi were responsible. Looking back, one is aware of the irony that it should have been necessary to go to Germany to observe a disease which, even if not obvious, is latent in every potato plant in America.

Orton devoted much attention to leaf roll which he likewise concluded was of the same nature: he failed to communicate the disease by graft, nor could he observe any evidence of its dissemination in the field. His work thus stands midway between that of Quanjer (Holland) and that of such workers as Appel (Germany), who first described leaf roll as a clinical entity in 1906, but thought it due to some unknown fungus, and that of Foex, 1914 (France), who thought that both leaf roll and curl were the consequence of some physiological breakdown in the plant itself.

The fungal nature of leaf roll was generally held at this time by workers in Germany and Austria, foremost amongst whom were Appel and Schlumberger (Germany), 1911, L. Köch and Kornauth (Austria), 1912, all of whom regarded a species of fusarium as the cause of the trouble. The latter workers represented a Commission which had been appointed by the Austrian Government specially to investigate this disease.

In Holland, Quanjer, who since 1908 had devoted much time to the diseases of the potato, now studied 'curl', and by careful field and glasshouse work distinguished several distinct maladies which had hitherto been grouped collectively under that name. His account of the histopathology of leaf roll, in 1913, is a landmark in our knowledge, showing, as it does, the vital part which the phloem plays in the movement of the virus in the plant. Quanjer succeeded in communicating the disease by graft to healthy potatoes, to the tomato, and many other solanaceous plants. Dykstra (U.S.A.), 1930, repeated the same, using *Myzus persicae* as vector. As early as 1912, he had

convinced himself that the disease was hereditary, i.e. conveyed through tuber sets, and was neither fungoid nor bacterial in origin.

Working in conjunction with Quanjer, Oortwyn Botjes, in 1920, showed that the green-fly transmitted leaf roll in the field; this was confirmed by Schultz and Folsom (U.S.A.) in 1921. In the same communication the latter investigator eliminated the soil as a means of transmission.

Quanjer's Institute at Wageningen may be said to have been the first school devoted to plant virus research; it has proved a source of inspiration to a whole generation of workers.

Englishmen were the first to recognize the existence of the problem, and the writer may perhaps be excused a brief sketch of his own early reactions to the subject. In 1906 experiments were begun on the genetics of the potato in his garden at Barley, Herts., which, excluding the period of the Great War, continued until 1925. The potato was chosen in the hope that it would prove a convenient medium. Theoretically it should have done so: in practice it proved otherwise. It was not long before it was discovered that, however healthy the seedling plants were when planted out in the open in May, by the end of the season many had begun to look unhealthy and dwarfed, whilst the majority of those carried into a further season by tuber were severely crippled, their leaves rolled or crinkled, the stems short and brittle, and the tubers generally reduced in size and number. At that time the writer knew nothing of virus, and indeed very little of plant disease in general, but it was obvious that he was faced by a problem of importance. He learned as early as 1909 from the late Arthur Sutton, who used to visit his experiments, that the trouble was well known to potato breeders and growers, and that it was referred to by them as 'miffiness'. In that same year there was growing a very promising seedling, H 7. Mr. Sutton admired it and the writer gave him some which he grew on in Scotland in 1910; he was assured that the 'miffiness'

present in some of the plants would be cured. In 1911 notes were made on H 7 and the trouble experienced from this 'miffiness' in which it was suggested that it might be due to physiological causes brought about by bad seed storage. Later, when some of the H 7 stock from Scotland was recovered and found to be still 'miffy' when grown at Barley, it was realized that this could not be the cause. In 1911, the writer laid down a long series of experiments extending over many years on the genetic basis of yield and other characters, involving tens of thousands of seedlings; in this he was joined in 1912 by James W. Lesley, now at the Citrus Experiment Station, Riverside, California. Before the War both had definitely come to the conclusion that the trouble was not due to senescence but was a diseased condition which could assume a chronic form.

The theory of senescence has a curious background implicit in most of the early writings on the subject. The argument ran somewhat as follows: Was it not obvious that the potato plant was furnished with competent male and female generative organs and could, and often did, give rise to normal fruits; and was it not a sin against nature to force upon a plant so cold-blooded a method of reproduction as propagation by tuber? What could one expect but a rapid decay of vigour in such unnaturally begotten offspring? Vigour and sexuality are cognate, and the psychological complex they induced managed to retard for the best part of a century the investigation of a problem in pathology.

The Great War brought plant virus research in Europe almost to a standstill. Quanjer's school, however, still functioned, and in a paper published in 1919 the result of their work in those war years is recorded. Amongst other things they distinguish between the primary symptoms of leaf roll which develop on the apical growths of a plant in the first year, and the general rolling of the leaves characteristic of second-year symptoms. Wortley, in Barbados, had already objected to this distinction, but it was several years after that Murphy, and later

Kenneth Smith, showed that second-year symptoms may be attained in the first year if the seed-tuber sprout is infected by means of the aphid *Myzus persicae* early in the season, an occurrence common enough in the sprouting sheds.

With regard to mosaic, they described an intensification of symptoms ending in extreme dwarfing and deformity, a condition which had been previously regarded as a distinct disease called curly-dwarf. Kenneth Smith has shown that this is the chronic result of infection with the 'Y' virus; and a similar effect has been shown by the writer and R. H. Le Pelley to result when a chronic infection with the paracrinkle virus is induced in susceptible varieties. Evidence was adduced to support the view that infection passed by the soil between diseased and healthy potato plants, and a controversy was started which has not yet been entirely settled. We realize now that in the case of the potato, Quanjer and his colleagues, and those who later held similar views in this country, were mistaken. Using phloem necrosis as his criterion, Quanjer thought that certain diseases of coffee, yellow stripe and sereh of sugar-cane, peach-yellows and rosette, and probably Japanese mulberry disease, were all alike in their essential nature, virus infections, a suggestion since proved to be correct.

Within a year of the close of the War, a new era of feverish activity in regard to plant virus research set in both in Europe and America. Our own knowledge and interest in plant virus research can be gauged by information to be found in the standard text-books on Phytopathology of the time. Massee in his *Diseases of Cultivated Plants and Trees*, 1915, records the work of Baur on *Abutilon* and writes that he 'considers this form of variegation or chlorosis is due to the presence of a virus depending on light for its formation'. Of leaf curl he says 'the cause is considered to be of a physiological nature, owing to the constant reproduction of the potato by vegetative methods'. Both these statements are reproduced without change from the 1910 edition of the same work.

Harshberger in his *Mycology and Plant Pathology*, 1918, speaks of curly dwarf potato in these words: 'It seems from our knowledge of the disease that it is a physiological disorder resulting in a permanent deterioration of the potato stock . . . perhaps senescence of the particular race of potato attacked, or in other words a varietal decline.' The same author speaks of tobacco mosaic as an example of a virus disease and adds: 'The view most generally accepted defines the disease as a disturbance of the enzymatic equilibrium induced by unfavourable conditions of growth.' If these excerpts, which are not made in any derogatory sense, are evidence of the limited and confused thinking on the subject prevalent at that time, they may serve equally to warn us that views held to-day may appear no less so when reviewed twenty years hence.

Two factors helped to make the immediate post-War period a turning-point in plant virus research in England: the one that a few people had become fully seized of the new pathological problem involved, and its economic importance to our potato crops. The other, that the potato variety Paul Kruger, which had been introduced into Holland in 1896, had now become popular in Great Britain under the name of President or such synonyms as Scottish Farmer and Iron Duke. This variety, which displays an almost uncanny susceptibility to leaf roll, had made the disease unpleasantly familiar to growers in all parts of the country.

At this period the writer, having become fully convinced that the degenerative diseases of the potato were due to specific infections and not to senescence, from 1919 onwards urged these views on the responsible advisers of the Ministry of Agriculture. Taylor was keenly interested but had still to be convinced; but in Cotton he found a sympathetic understanding of the problem. Cotton, Fryer, the Ministry's entomologist, and Pethybridge, then mycologist at Dublin, had attended the International Phytopathological Congress in the U.S.A. in 1919; Cotton had returned filled with a missionary fervour for studying virus disease and for the importance of the progress already

made in Holland and America. In 1921, Cotton initiated experiments on the infectivity of potato virus diseases at Kew. Fryer ably seconded Cotton, and Pethybridge, who had earlier been a protagonist of the fungoid theory of leaf roll, was converted to the new views and from that time took a keen interest in the development of plant virus research in Great Britain.

In 1920 the appointment of Kenneth Smith and Holmes-Smith by the University of Manchester to investigate potato curl, the one as entomologist, the other as mycologist, marks the first step in England towards plant virus research.

Whilst in England we were beginning to feel our way in this new field of research, a young Irishman, Paul Murphy, had already made substantial progress. Murphy received his education in Dublin and at the Imperial College of Science in London, had graduated in 1913 and proceeded to Germany, which he left at the outbreak of the War. On medical grounds he was refused by the army and proceeded to America, where he studied some time at Cornell and then took up the post of plant pathologist in Prince Edward Island, under the Canadian government. Here he was directly concerned with the potato crop and in particular with the seed trade which had been locally developed. By his own research and in conjunction with Wortley, investigations of importance both in the laboratory and in the field were inaugurated. Before he left Canada, in 1921, to take up a post at University College, Dublin, where he became Professor of Pathology in 1927, he had acquired a position in the front rank of virus workers. In Canada, under Güssow, the government botanist, Murphy had organized a service of inspection and certification for the production and distribution of virus-free potato 'seed'. Copied and developed by the agricultural authorities in Scotland and Ireland, this action of Murphy's has done more to improve the potato crops of Great Britain and the Dominions than any other single measure. We shall have occasion to refer to other contributions made by Murphy to the study of plant

virus diseases, but here I may be allowed to record the regret felt by his co-workers at his all too early death in September of last year.

The seed had been sown: the first evidence of its germination is to be found in the International Potato Congress called together by the Royal Horticultural Society in November 1921. A survey of its proceedings gives a complete cross-section of expert opinion at this date.

Sir A. D. Hall's Inaugural Address was read, in his absence abroad. Having dealt with the place of the potato in crop rotation, and the ease with which the crop could be increased, he discussed the question of healthy seed-supplies, expressing his opinion that the new research on virus disease would lead to the discovery of the essential factors controlling its production; he felt assured that suitable situations outside the well-known Scottish and Irish seed areas would be found in Wales and elsewhere—a prophecy which has come true. Armed with the new knowledge on leaf-curl and mosaic which had reached us from America and Holland, he hoped that we might breed varieties immune both to the common blight and to curl, as we in England had succeeded in doing to wart disease.

Of the several papers touching on the virus problem was one by the writer on 'Degeneration of Potatoes'. After giving an historical sketch of the subject, he dealt with the theory that the so-called degenerative diseases were due to senescence. He showed that the genetic cropping capacity of any individual potato can be measured by a curve recording the classes of the relative yield of its selfed seedlings, the relative yield being the relation between the actual yield and the size of the haulm; and such were grouped into five classes. This curve is a constant one, unaffected by the existence or otherwise of curl or leaf roll in the particular individual under observation. Two remarks may be quoted as still of value: 'The explanation which is offered of the constancy of the cropping classes in families derived from the same parent, both when healthy and when "degenerate", is that the degeneracy is

due not to a gradual and increasing senility but rather to an infection which by reason of the anatomical severance of the embryo from the mother tissues is unable to obtain access to the former', and later, 'In a word, immunity to mosaic is the key to immortality—for the potato.'

The outstanding feature of the Conference was the presence of Professor Quanjer, who read a paper on leaf curl and allied diseases, the first authoritative exposition in England of his work. He distinguished the various clinically distinct affections of the potato and communicated the recently proved fact of virus transmission by aphis. He pointed out that solanaceous weeds might act as carriers of leaf roll in the field.

Quanjer took this occasion to retreat from his earlier views on infection through the soil, ruled out both physiological deterioration and enzymatic disturbance as causes, and declared that the symptoms 'can only be explained by the hypothesis that there are a number of micro-organisms causing them'. He discussed the possible existence of ultra-microscopic organisms common to the troubles of the potato, tobacco, and those other plants whose filtered juices had been shown to be infectious. Quanjer told how there were areas in Holland where potatoes suffered but little, and that these were near the sea where the air was moist and the winds strong, a fact which was to find its explanation in the work of the late Maldwyn Davies (Bangor), 1932–8, who showed that the alate aphis did not take to the wing when the air was laden with moisture and the velocity of the wind above 8 miles per hour.

Murphy followed with a paper on his work in Ireland, the abnormalities in starch translocation in leaf roll, the variation of symptoms due to external temperature, and the occurrence of carriers. He was convinced that these diseases were due to a living parasite which might be ultra-microscopic.

Cotton reviewed the virus problem, as a whole, and described the experiments he had initiated at Kew, in 1920, and the trials of healthy and diseased 'seed' which the Ministry had set up at twelve agricultural centres in

order to demonstrate to the farmers the seriousness of the disease and the value of clean seed. He emphasized the importance of the green-fly in the dissemination of these diseases and the necessity of determining the species responsible in each case; he asked for a survey of the British Isles to establish the incidence, relative abundance, and dates of appearance of the various species of aphis, a survey we are still anxiously awaiting!

Orton discussed the work done since 1912 in the U.S.A. on virus diseases of the potato, and referred to the fact that in some cases leaf roll might be recognized in the tuber by the presence of net-necrosis, itself due to the destruction of the internal phloem. In 1938, Dennis (Cambridge) showed that the reason why it was not a constant feature was that it occurs only when both the virus of leaf roll (Sol. vir. 14) and of Virus A (Sol. vir. 3) are present simultaneously.

The Congress had come at the critical moment, when the clouds of pseudo-scientific speculation which hitherto had enwrapped these problems were breaking and a few young and active workers salvaged from the War were ready for the new light.

The future of this research in England, however, might have been very different had not Hall, at this juncture, been Chief Scientific Adviser to the Ministry. In him we had a man of wide knowledge, great administrative experience, a capacity both for original thought and the understanding of new ideas, and, above all, the supreme gift of inspiring others. This meant the coming of a new spirit in the relation between the Ministry of Agriculture and plant research: not that everything happened at once, but the ferment which then began to work brought about notable results, nor has his inspiration exhausted its influence.

The Congress survey is supplemented by Cotton's report to the Ministry of Agriculture on bacterial and other diseases of crops in England and Wales, during the years 1920–1, published in 1922. From this it appears that a good start had been made: an inquiry had been

instituted into the widespread character of virus diseases in the potato crop; mosaic was noted for the first time in sugar-beet, raspberries, runner beans, and mangolds; differences in varietal susceptibility were observed in the two latter. Cucumber mosaic had been recorded in the glasshouse, and experiments on its infectivity undertaken by Bewley and W. Buddin. Chittenden had listed some thirty susceptible varieties of dwarf beans susceptible to mosaic at Wisley. An epidemic of mosaic in tomatoes had occurred in certain glasshouses and was being studied by Bewley, at Cheshunt; tobacco mosaic had occurred in 1920 in a commercial crop in Norfolk, and successful sap inoculations made by Bewley. The 1921 tobacco crop was free from mosaic, and it was assumed that the attack in 1920 had been contracted from an adjacent potato-field. In such case the virus trouble of the tobacco would in all probability have been due to the 'Y' virus (Sol. vir. 2), and not to the virus of tobacco mosaic.

In 1924, the Ministry of Agriculture appointed a special committee to consider further extension of research in plant virus disease, and this body, enlarged and strengthened in 1927, has kept a watching brief for the activities of virus research workers ever since. The Agricultural Research Council, founded in 1931, to which this committee is now attached, has exercised a wise discretion in regard to the selection of material to be studied at each Station, and has attempted, not unsuccessfully, to prevent undesirable overlapping. At first there was an attempt to segregate at Rothamsted what was termed fundamental virus research, and to leave the more practical and field problems to other Stations. It is well to record that this policy has not been unduly stressed; the trend of research must always depend on the character and temperament of those engaged on it; the man is always more important than the Institute. It is more than a coincidence that perhaps the largest share of research which may be regarded as fundamental in character has emerged from the Station to which the most mundane task was originally allotted.

Before 1920, such consideration as had been given to virus disease in this country had been confined to the potato. From now on, the importance of similar infections in tomatoes, legumes, and an ever increasing number of our horticultural plants, gained recognition.

In 1927 we get another bird's-eye view of the position of plant virus research in Great Britain on the occasion of a Conference held under the auspices of the Development Commission. Henderson Smith (Rothamsted) outlined the character of work he hoped to pursue on the nature of the virus, but he was still awaiting a glasshouse. He had studied the organism thought by Bewley to be the cause of tobacco mosaic and had failed to confirm it as such; he had attempted to cultivate the virus outside the plant without success. It may be mentioned that no one has so far succeeded in doing this. White (Bangor) outlined Whitehead's work on leaf roll, the correlation of degeneration with susceptibility to virus disease. The examination and selection of areas where degeneration of potato stocks does not occur was being followed up. Anderson of the Department of Agriculture for Scotland stated that the Scottish Society for Plant Research was attempting to breed potato varieties that were tolerant to virus disease. Bewley gave his reasons for believing that the mosaic diseases of cucumber and tomato are to some extent seed-borne. It was known that Kenneth Smith in Manchester had worked out the details of the mechanism of the feeding of aphids and allied insects, and the all-important part played by the peach aphid *Myzus persicae* in conveying leaf roll. He had also observed inclusion bodies in the cells of the leaf of a mosaic-infected potato.

Kiernan, representing the Irish Free State, gave an account of Murphy's work on the symptomatology of the various virus potato diseases, and the close liaison maintained with Wageningen whereby the identity of the diseases investigated at either Station had been established. Stress was laid on the necessity of using virus-free potatoes for testing purposes. The existence of carriers, the spread of diseases in the field, infection by aphids on

the sprouts of store potatoes, and the rate of spread of the virus within the plant, were all subjects under investigation. The organization of healthy seed production had been put on a commercial basis.

Hall urged the desirability of conducting a survey of Great Britain to show where potatoes might be grown free from disease; he was confident that the conditions under which one virus might be combated did not necessarily hold good for another. Throughout the discussion Hall emphasized the necessity of research into the nature of virus disease in itself, to be carried on at one definite Station, feeling that it would give inspiration to those engaged in the more practical problems of horticulture. He felt that there must be some common background to all these diseases, no matter in what climate they occurred, and urged that the ultra-microscope of Barnard and all that it implied must be made available to plant virus workers as well as to the few researchers at Hampstead.

A welcome feature at a conference devoted to botanical problems was the presence of the late Sir Walter Fletcher and the late Captain Douglas, who both reported on the state of progress in animal virus research and the possible points of contact with the plant virus worker. Douglas insisted that we must dismiss from our minds much of the theory of bacterial infection and immunity and realize that a virus 'may be something quite different'. The concluding paragraphs of this essay will show that his words were more prophetic than we had realized at the time.

Throughout the Conference the Government, through its chief advisers and by the presence of the Under-Secretary for Scotland, Walter Elliot, evinced the keenest interest in the problems, theoretical and practical, which were raised, an interest which was maintained for several years.

From now on, English workers are to be found studying virus infections in most of our horticultural crops. The work of some has already been mentioned and that of others will be referred to elsewhere in this paper. The following, however, may serve to illustrate the importance

of the research being undertaken and its economic value to the country.

Salmon, at Wye, who began his studies on hops in 1923, has, in conjunction with his colleagues Cheal and Wade, been responsible for most of our knowledge of the virus disease of this plant, no less than for the best new varieties. Amos, Hatton, Knight, and Massee at East Malling, in 1927, attacked the problem of reversion in black currants and showed that it was due to a virus carried by the Big Bud mite. Since 1931, the two latter workers have made an intensive study of the virus diseases of the strawberry, yellow edge, and crinkle, which they have shown to be conveyed by the strawberry aphis. Ogilvie, at Long Ashton, who in Barbados had done valuable work on aster yellows and virus diseases of the lily and their control, 1925–8, has been instrumental in tracking down new virus infections in the country-side, notably crinkle in strawberry and a virus disease of lilies. This latter Station has made a special study of the mosaic of lettuce and shown that its vector is an aphis and that it may also be transmitted by seed.

We may now attempt to follow the progress of research in plant virus diseases generally, especially during the last decade, noting in the main only such observations and experiments as appear to have had a directional effect on the progress of our subject, but in so doing it is feared that less than justice may be done to much other excellent work. For the sake of simplicity the subject-matter will be described under a few group headings.

The plant world and virus infection: The field of observation which in Europe had been almost confined to the potato, but which in America had included other plants such as tobacco and the peach, is now greatly enlarged. Monocotyledons, including the sugar-cane, maize, wheat, rye, pineapple, banana, and the lily tribe, have all been found to be subject to virus attack. That affecting the sugar-cane has had far-reaching economic reactions throughout the world. Loss of crops due to virus disease had been serious, but breeders in Java ultimately pro-

duced canes highly resistant to mosaic infection known as P.O.J. 2714, 2725, &c.: the result has been so to increase the output and to reduce the world market price that cane culture is no longer profitable. Maize, too, is subject to more than one virus infection, much of our knowledge of which is due to Storey, working at the Amani Station in Tanganyika.

Amongst dicotyledonous plants, there are few genera in which some virus infection has not been observed. No virus infection of the cryptogams has been reported.

The infective range of a virus: Whilst some viruses are confined more or less closely to a particular family of plants, others have an almost unlimited host range. Notable amongst these are the virus of yellow asters, studied by Künkel (U.S.A.), and that of spotted wilt by Kenneth Smith, at Cambridge; this latter being one of the few which pass readily from dicotyledonous to monocotyledonous hosts, it attacks most of our glasshouse plants and has occasioned very serious monetary loss to the industry. The same virus is also to be found affecting such common weeds as the plantain and the bindweed. It is conveyed by several species of thrips. Cucumber mosaic (Cucum. vir. 1) has perhaps the widest range of host plants and is one of the commonest causes of virus disease in the flower-garden.

The geographical distribution of a virus: In these days of rapid and facile communication it is not surprising that a given virus may be found in places as far apart as Australia and England or, as in tobacco mosaic, wherever the host plant is grown.

Even when a virus is confined to a single host, such as the bunchy-top virus of bananas, it may be found in places as distant from each other as Egypt and Queensland. At Cambridge, Dennis has shown that potatoes sent straight from Puno, on Lake Titicaca, in Peru, may be infected with the same viruses, and even with similar strains of those which are found in our English potatoes.

Methods of transmission: Infection by sap inoculation, whether experimental or brought about in nature by leaf

abrasion (no less than infection by insect transmission), was of course well known, but in late years the suggestion has been made both in reference to common tobacco mosaic (Nicot. Vir. 1) and tobacco necrosis (Nicot. Vir. 2) that such might take place through the air by means of the leaf stomata. The weight of evidence is against the acceptance of this view, but we do now know that the least trauma, such as the breaking of a 'hair', is sufficient to allow of ingress to the virus. Recently Kenneth Smith has shown that particles of tobacco necrosis virus may be isolated from the air in a glasshouse in which a small quantity of infected matter has been previously introduced in a fine spray, and has shown reason to believe that such finds its way to the soil in which tobacco seedling plants are growing, whence it may be washed down to the root fibres and infect them. Infection through the soil, however, is a rare phenomenon. A prerequisite seems to be an abrasion of the root fibres of the healthy plant by which the virus washed out of the rotted remains of the infected plant left over in the ground may gain ingress. In this way it is possible that tobacco mosaic may be spread, apart from such that follows normally by leaf contact and the like. No evidence has been found at Cambridge of infection through the soil by any of the virus diseases of the potato.

The relation of insect vector to the virus and to the plant: A great deal of work has been done on the relation between virus and insect, especially by Mrs. Watson (Rothamsted). That the transfer in many cases is not merely mechanical is certain, but whether there is any true incubation stage, as was previously supposed, is still unproven. Mrs. Watson's work suggests that some reaction takes place in the intestine of the aphis between its juices and certain viruses which it has ingested, which destroys the latter, with the consequence that the longer an aphis feeds on the diseased plant, the less potent is it to infect. On the other hand, in spotted wilt, Samuel and Bald (Australia) have shown that it is only in the larval state that the thrips picks up the virus which, when adult,

it still retains. In this insect there is a delay of about a week between feeding and the acquisition of infectivity. One of the most interesting observations of this kind is that of Storey, working at Amani, in connexion with the jassid *Cicadulina mbila*, the vector of maize streak. He has shown that individuals may be active, i.e. capable of conveying infection, or inactive, i.e. unable to convey, and that activity is controlled by a dominant sex-linked hereditary gene. If an inactive insect be punctured through the abdomen, and survive, it becomes active. Similar results have been obtained by Merril and Tenbroeck (U.S.A.), 1935, with the virus of equine encephalomyelitis, and the mosquito *Aedes aegypti* which normally only transmits the western variety of this virus. If, however, the abdomen of the mosquito be punctured, it will henceforth transmit both. Hitherto there has been no evidence that an infected insect ever transmits the virus to its offspring, though some recent work of Fukuski (Japan), 1935, indicates that the virus of dwarf disease of rice may be conveyed by an infected mother leafhopper to some of her offspring, but that an infected male has no such power. Recently, Storey has shown that the capacity of an insect to give a plant an infective dose is an inherent but variable quality, and that in maize the virus is only effective if the insect's proboscis enter the phloem; even so, the insect must eject a minimum quantity of virus at any one puncture. Bennet and Carsner, and Lackey, in America, have also contributed much valuable information along similar lines.

The distribution of virus within the plant: In the early days of virus research, systemic diffusion of the virus throughout the plant was established in the mosaic diseases of tobacco and potato and was accepted as being true for plants in general. Of late, several exceptions have been noted. Bennet (U.S.A.) has shown that in curly-top of sugar beet the virus is confined to the phloem, and Storey that in streak of maize the virus may be found in both phloem and mesophyll but only in those parts which are chlorotic. Bennet (U.S.A.), 1937, by girdling

experiments in the raspberry, showed that the virus of curl moves in the phloem. Caldwell (Rothamsted), 1930–2, adopting similar methods, has investigated the mechanism of virus translocation in the tomato, and has shown that such does not take place in the xylem. In fact, if the xylem vessels be injected with infected sap the plant remains unaffected. The phloem can convey, but his experiments went to show that the virus travels generally from cell to cell in the mesophyll. To-day, it seems probable that the virus actually passes by plasmodesmen from cell to cell till it reaches the phloem and, where such does not exist, as in the guard cells of the stomata, no transference takes place.

There are numerous cases where, as in infection of common tobacco mosaic in *N. glutinosa*, the virus remains localized at the points of entry on the inoculated leaf, but more peculiar is the behaviour of the tobacco necrosis virus which Kenneth Smith has shown remains localized in the root tissue of the tobacco plant, never extending into the aerial parts of the plant, whilst those same leaves may be artificially inoculated with sap taken from its own roots.

Recently Miss Sheffield (Rothamsted) has shown how very unequal may be the quantity of virus contained in a 'cleared' vein, as compared with that in the 'banded' portion of an older leaf, when infected with the virus of Hyascyamus III.

A problem of much economic importance is the possibility that the seed of an infected plant itself may be infected. That such does occur in a varying percentage of cases in bean mosaic and lettuce mosaic is certain. Occasional transference of virus by seed is reported in cucumber infected with mosaic; that such transference takes place in the tomato is still maintained by Bewley.

In 1921, Blakeslee (U.S.A.) reported a case in which a virus disease appeared to be transferred by pollen to the next generation. Reddick (U.S.A.), in 1931, showed that in bean mosaic there was good reason to believe that this might occur. Transmission whether by the ovule or by pollen would seem, however, to be a rare event.

Unit Diseases due to virus complexes: Kenneth Smith (Cambridge), in 1928, had found that from a potato affected with 'mosaic' he obtained two distinct reactions on tobacco, according to whether he transferred by needle inoculation or by aphis. In 1929, he again recovered from a potato, this time suffering with crinkle, two distinct viruses. Koch (U.S.A.), 1931, obtained similar results from a potato suffering from rugose mosaic. Murphy (Dublin), 1931, demonstrated that in the potato in the field such combinations occurred naturally, and that one such explained the disease he had described earlier as crinkle. By a curious coincidence, the writer produced evidence at the same meeting of this Congress of the fact that a clinical crinkle indistinguishable from the common field form could be induced in the glass-house by the combination of yet another pair of viruses. Since then, such virus complexes have been recognized as common, particularly by American workers.

Inclusion bodies: Controversy as to whether the intracellular inclusions in plants infected with certain viruses, notably those of common tobacco mosaic and the 'X' virus of the potato, were living organisms, possibly protozoa, as advocated by Goldstein (U.S.A.), has now been brought to a close. Sheffield and Henderson Smith (Rothamsted) examined the living hair-cell of a leaf of *S. nodiflorum* infected with the aucuba strain of tobacco mosaic, and by means of a cinema-camera obtained a continuous record of the genesis and fate of an X-body in being. In this way it is possible to see the body being built up by the aggregation of wandering particles caught up in the streaming cytoplasm of the cell. Miss Sheffield has now succeeded in removing an X-body from the cell, washing it and estimating the quantity of virus in it, which she finds to be very high. There is reason to think that an inclusion body contains a large excess of virus particles.

Multiple strains of a virus: Perhaps the most voluminous chapter in the bibliography of plant viruses is concerned with the recognition that there exist groups of viruses possessing a large number of characters in common but

differing one from another, perhaps, in a single reaction. It has often happened that for many years a particular virus has enjoyed a specific status only to lose it as its physical and other properties have become more exactly studied. The best-known series of virus strains are those of tobacco mosaic, many of which have been described by Johnson (U.S.A.), Holmes (U.S.A.), Kenneth Smith (Cambridge), Bewley (Cheshunt), and Ainsworth (Cheshunt). Price (U.S.A.) has described a very large number of strains of cucumber mosaic. The writer has dealt with Sol. Vir. 1, or the 'X' virus, and has isolated in what appears to be a pure state six different strains, and has shown reason to believe that they are differentiated by the possession of distinct radicles. Until one can demonstrably induce a mutation in a virus particle—hitherto we can only indirectly infer that such has occurred—the relation between the putative parent virus and daughter strain must remain obscure. Bawden and Pirie (Rothamsted and Cambridge) have drawn attention to the fact that Ainsworth's cucumber viruses, Nos. 3 and 4, whilst not infectious to tobacco, have nevertheless many properties, serological and physical, in common with tobacco mosaic virus. Price showed that a mosaic virus of the lily, by continuous passage through tobacco, assumes all the characteristics of Cucum. vir. 1. These facts suggest that a strain of a virus may become so closely adapted to a secondary host as either to acquire new or, alternatively, lose certain of its parental characters and thereby attain an independent specific status.

Acquired immunity: The writer, in 1933, demonstrated that infection of a host with a non-virulent strain of a virus protected it against subsequent infection with the most virulent strain of the same virus. A blocking effect between two virulent strains of tobacco inoculated consecutively on the same plant had been noticed by Thung (Java), in 1931, but the observation had escaped general notice. The protection phenomenon has been confirmed in a large number of viruses and their strains, and it is now generally accepted as a criterion of the relationship

between any two viruses affecting the same host. The writer has pointed out that this type of immunity is entirely different from the humoral immunity seen in animals and that it plays, and has presumably played for hundreds of years, an important part in the preservation of the potato.

New methods of research: Holmes (U.S.A.), in 1930, introduced the method of comparing the virus content of two suspensions of a like virus by counting the number of local lesions produced on a susceptible host. The method has proved of great value and has been used by workers everywhere. Of late it has been duly refined, and for the non-mathematical biologists complicated, at the hands of the statistician. Bald (Australia) has shown the limits of dilution of virus suspensions within which the results are reliable. The notion that a local lesion represented the infection by a single virus particle is no longer tenable, and the fact, referred to later, that the size of a particle may be determined by the treatment of the fluid in which it is suspended, has emphasized the necessity of limiting the comparison of virus suspensions strictly to those which have been prepared in like manner.

The serological approach: On the assumption that the virus was a protein body and distinct from those of the normal plant, specific antigenic sera have been prepared in rabbits by the intravenous injection of purified virus suspensions. The first to adopt this method was Dvorak (U.S.A.), 1927, with potato mosaic; the method was extended by Helen Purdy, now Mrs. Beale (U.S.A.), 1929, who produced antigenic sera to tobacco mosaic and obtained precipitin and complement fixation reactions, and by absorption methods removed such antigens as were common to the protein of the healthy plant. K. S. Chester (U.S.A.), 1932–8, has greatly extended our knowledge of plant serology: he demonstrated the existence of distinctive antigens in the different strains of tobacco mosaic virus, and applied the very sensitive anaphylactic reaction to plant virus problems. The method was used by Gratia (Belgium), 1933, and was introduced

to this country in 1933 by the writer in conjunction with Spooner, of the Department of Pathology, Cambridge; the writer's place was taken over at an early stage by Bawden. They have studied the serological varieties of several plant viruses and their strains, observing in the latter certain differences in the antigens present. They have also succeeded in developing the technique so as to make it a ready means of determining within a few hours the identity and, with a high degree of accuracy, the concentration of any particular virus suspension. A method suitable for use in the field for determining the nature of the virus present in any infected plant has been elaborated by Chester, 1936.

The control of plant virus diseases: This has been attempted in a variety of directions of which the following is but a very brief summary:

Destruction of the virus: Kunkel appears to have actually succeeded in destroying the virus within peach-trees infected with peach yellows, by the treatment of the trees in a water-bath for 10 minutes at a temperature of 50° C. or in glass-houses at 36° C. for ten days.

Protection against insect vectors: The treatment of growing crops by nicotine sprays is in general too expensive, but Mrs. Watson, by spraying commercial Henbane plantations, has materially increased the output of this valuable crop. Kunkel (U.S.A.) has successfully used low vertical screens to keep the jassid vector off aster yellows, and Lesley (U.S.A.) has employed a similar protection with some success against tomato yellows.

Protection against accidental sap inoculation: Of all vectors, man himself is the most dangerous. It is through the infected juice on the hands of the attendant who 'stops' and tends the tomato plants that mosaic spreads in the glass-house: by the same agency, much assisted by the habit of tobacco-chewing with its consequent habit of expectoration, the virus of mosaic is spread throughout the tobacco-fields of America. Supplying the attendants with rubber gloves and antiseptic solution with which to rinse their hands, together with the prohibiting of chewing

and smoking whilst on duty, has had highly beneficial results.

Removal of overwintering sources of virus infection: This may be done in several ways: thus, in the potato fields the major source of infection is from ground-keepers persisting from previous crops: efficient cultivation is the remedy. In other cases it may be weeds which carry, often in a symptomless manner, a virus which may play havoc with a cultivated crop. Thung, in Java, has almost eliminated tobacco curl by the removal of carrier weeds. In Florida, the celery crop has been protected against the cucumber virus by the removal of the weeds *Commelina nudiflora* and *Phylotocea Americana*.

The acquisition of acquired immunity: The writer has shown that it is easy to protect the potato against attack of the lethal strains of the 'X' virus (Solan. Vir. 1), by prior inoculation with a symptomless strain 'X^H', and that in nature protection has been obtained in this manner. How far the method is capable of extension is doubtful.

The cultivation of carrier strains of economic plants: Many potato varieties which have attained popularity are themselves infected with viruses fatal to other varieties. Could we obtain a variety which was capable of carrying without danger to itself the chief viruses which affect the crop, then the cultivation of carriers might be a safe and practical method of solving the difficulty. It must, however, be remembered that virus carriers may be a very real source of danger to susceptible plants, especially in commercial glass-houses. Salmon found that the Fuggles variety of Hops was a carrier of the mosaic virus, and though valuable in itself, was a danger to non-carrying varieties in the gardens.

Breeding of resistant varieties of plant: Of all methods of control the breeding of varieties, economically suitable and at the same time resistant to virus attack, is the best. In a few cases success has been obtained. A notable example has been referred to in the P.O.J. sugar-canes. Zaumeyer and Wade (U.S.A.) have produced several types of beans resistant to the more destructive of the viruses which

attack leguminous plants. Cucumber varieties have been bred resistant to the cucumber virus, and sugar-beets resistant to curly-top. There is reason to hope that we may obtain similar success in time with the potato. Already a variety has been bred in America which is immune to all strains of the 'X' virus.

Holmes, 1935, has studied the resistance offered to tobacco mosaic viruses by peppers and various nicotiana species and their hybrids, and has shown that such is controlled by genes operating on Mendelian lines.

Perhaps the most effective example of such control is the Sakellarides cotton selection, X 1530. Lambert, Inspector of the Observation Section of the Gezira Cotton Area of the Sudan, selected, in 1926, the seed of a particular plant which showed outstanding vigour. At that time leaf curl was almost unknown in the Sudan, having made its first appearance in 1924 when it was observed in a few isolated places. Four years later the disease had spread throughout the entire 200,000 acres under cotton, causing a loss of at least 30 per cent. of the crop. The Lambert Selection was grown on by Bailey, Plant Breeder to the Sudan Government, who continued the selection with a view to improvement of quality and crop, and only later because of its resistance to virus infection, which had not been suspected when the seed was originally saved. In 1934, the X 1530 occupied about 500 acres, in 1935 13,000 acres, and to-day the area under X 1530 in the Gezira is 100,000 acres. The rest of the district, being relatively free from white-fly, is still sown with the old Sakel variety which, though susceptible and inferior in yield, is better in quality.

The virus particle: its size and nature: There has been no more exciting chapter in biology than that which has dealt, in recent years, with the ultimate nature of the plant virus particle. That the virus was particulate was obvious from the fact that, though one Berkfeld filter might allow the passage of virus, a still finer one failed to do so having removed all infective material from the sap. To obtain a more accurate knowledge of the dimensions of

plant virus particles, Kenneth Smith adopted Elford's gradocol membrane ultra-filtration method, and has succeeded in establishing the approximate size of several. Thus, tomato bushy-stunt virus has a diameter of 14–20 mμ, common tobacco mosaic 25 mμ, and that of the potato mosaic virus about 100 mμ. The shape of the virus particles in these estimations was assumed to be spherical. Inasmuch as the two latter have now been shown to be rod-shaped, the figures for them can only be regarded as approximate. They do indicate, however, how minute the virus particle may be. A bacillus prodigiosus with a diameter of 750 mμ has a volume some 53,000 times as great as that of the virus particle of tomato bushy-stunt.

Takahashi and Rawlins (U.S.A.), in 1933, observed by means of polarized light the phenomena of stream double refractions in the sap of mosaic-infected tobacco plants, and suggested that it was due to the presence of rod-shaped virus particles. Later, they were doubtful of the validity of their evidence, but in 1935 they reaffirmed the essential relationship between rodlike particles of tobacco mosaic and stream double refraction. Stanley (U.S.A.), in 1935, isolated by precipitation methods from the sap of tobacco mosaic plants a highly concentrated suspension of virus which exhibited characters of a para-crystalline nature. In 1937, Stanley and his colleagues Wyckoff and Loring isolated a similar protein substance from the clarified sap of tobacco mosaic plants by means of high-speed centrifugation. This substance was intensely active and they claimed represented the virus.

It was found that this protein substance possessed certain properties such as anisotropy of flow, suggesting its rod-shaped character. Further work led to the view that they were dealing with a giant protein molecule which was, in fact, the virus and that in the ordinary meaning of the word it was non-living. In this country Bawden, together with Pirie, repeated the work on tobacco mosaic virus, extended it to the potato virus 'X' and to the bushy-stunt virus of tomato, from all of which they

obtained protein bodies which they showed were composed of a nucleo-protein with a carbohydrate radicle. The concentrated suspension of the potato virus showed anisotropy of flow in much the same manner as did tobacco mosaic. From the bushy-stunt virus, however, they isolated genuine rhombic dodecahedral crystals: this virus, being spherical, showed no anisotropy of flow. Bernal and Fankuchen joined forces with Bawden and Pirie and subjected these proteins to X-ray analysis. Bernal concludes 'that the separated virus particle has an internal crystalline structure of great regularity and this structure is analogous to that of other crystalline proteins'.

From the work of these authors and from Smith's filtration experiments it is certain that virus particles can aggregate as in the case of tobacco into elongated rods, and that the degree of aggregation varies with the method of preparation, hence the uncertainty of the gradocol filtration results.

The isolation of these crystalline nucleo-proteins, which it would be pedantic to refuse to accept as being the viruses themselves, has raised the question of the relation of viruses to such organisms as bacteria and, in particular, the problem of whether they are to be regarded as living or not, and in what manner they reproduce themselves within the host cell. Stanley suggests that the viruses arise by an autocatalysis of pre-existing allied proteins within the host cell which would thus create the agent by which its own destruction is effected. There are several objections to such a view, apart from the fact that we are loath to depart from the principles of biogenesis which have never failed us so far. It may, however, be argued that so long as we are dealing with substances, however complex, which can be isolated and crystallized, and which are identical with certain viruses, we are not dealing with organisms and the question of heterogenesis versus biogenesis does not arise. However, there is no reason to believe that the viruses, the diameter of whose particles range from 10 $m\mu$ to 275 $m\mu$, are all of the same structural nature. Indeed, the evidence is against such

an assumption, for Bedson (London University) has shown good reason for believing that something in the nature of a life-history can be made out for the large virus of Psittacosis.

An alternative theory elaborated by Laidlaw (England), 1938, forms a bridge between the two views. His suggestion is that the smallest viruses are the last links in a chain of ever-increasing parasitism which, in effect, is a progressive loss of specific enzymes capable of autosynthesis. Although they have lost all the essentials of living matter possessed even by organisms so low in the scale as bacteria, viruses still retain the chemical basis which transmits the character of the species. This they can do only within the appropriate host cell by acquiring the necessary enzymes ready made from the host. The damage exhibited by the host tissues, it is suggested, may be due to the withdrawal of these bodies from their normal function.

Like a famous Encyclopaedia whose first volume begins with 'Aach' and whose last ends in 'Zweifel', so, I fear, does this sketch. At its inception, we saw the virus problem enwrapped in a fog of mysticism from which, by the untiring pursuit of scientists the world over, it has emerged. Now, at the close of our tale, we find the virus particle leading us direct to the shrine of the greatest of all mysteries, the origin and meaning of life itself.

PLANT PROTECTION

By J. C. F. FRYER

AT the beginning of the twentieth century agricultural entomology and phytopathology had only just begun to take their places as definite branches of agricultural science. The study of the sciences basic to them—entomology and mycology—had been generally neglected at the universities and progress in their adaptation to economic ends had been left to a small number of devoted pioneers. On the entomological side, Curtis, Ormerod, and Theobald, and on the mycological, Berkeley, Cooke, and Massee, are outstanding examples of that very small band of scientific workers who in the period between 1810 and 1910 carried almost the whole burden of research and advisory work in economic entomology and mycology. With the early years of the twentieth century, however, the first signs of a change can be detected, and there seems to have been a growing realization that the attention given to plant pests and diseases was inadequate to the needs of the time. The fundamental reasons which brought this need to the surface precisely at this period are not very clear: doubtless agriculturists who were already receiving substantial practical assistance from other sciences, notably in relation to artificial manures, felt that similar help might be forthcoming in respect of phytopathology, but this explanation is hardly adequate, and at least a contributory reason may be seen in the reports then being received from the United States of America, where greatly increased attention was being given to plant pathology and entomology, largely as a result of the depredations caused by introduced diseases and pests. The introduction of American Gooseberry Mildew into Great Britain, and the rumours of the losses caused to fruit-growers in America by the San José Scale, brought home to agricultural opinion in England the dangers to be apprehended from the introduction of foreign pests and diseases, with the result that in 1907 Parliament was persuaded to pass the

first comprehensive Act dealing with 'destructive insects and pests' (the Act of 1877 having been confined solely to the Colorado Beetle). The issue under the Act of 1907 of an Order, with its schedule of notifiable pests and diseases, gave rise to an immediate demand for the identification of 'suspects', and naturally an inquirer was not satisfied with being told that his trouble was not due to any scheduled pest, but he also wished to know what was responsible and still more how to prevent further losses. The demand by the public for assistance regarding pests and diseases soon received official recognition, and in 1910 the Board of Agriculture sent to the Treasury a letter (subsequently printed and published) in which was written: 'Of the subjects on which advice is required, the most important are those bearing on the treatment of crop diseases. The correspondence of the Board and the experience gained in the administration of the Destructive Insects and Pests Acts show how urgent is the need for scientific assistance.'

At that time the official consultants to the Board of Agriculture were Dr. McDougall, of Edinburgh, for entomology and the late Mr. Massee, of Kew, for phytopathology, while outside the official sphere were the late Professor Theobald and Professor Salmon, both of Wye, the consultants to the Royal Agricultural Society (Mr. Warburton and Sir R. Biffen), and one or two others. That so small a body of men could cope with the growing demand for assistance from the agricultural industry, and notably from its rapidly expanding horticultural section, was clearly out of the question, and the quotation from the Board's letter to the Treasury can readily be understood. Fortunately the Government of the time had already been convinced that increased attention to agricultural science was essential, and the passing of the Development and Roads Improvement Funds Acts, of 1909 and 1910, marked the beginning of a new epoch for agricultural entomology and phytopathology as for other sections of agricultural science. The development of the research and advisory 'services' under this and subsequent Acts

is described in an earlier essay in this book, and there is no need to cover the same ground here, but it is necessary to refer to certain factors which led to the evolution of phytopathology and entomology along lines somewhat different from those of the other agricultural sciences.

In the first place, the study of both of these subjects necessitates more extensive field work than many other subjects. The plant breeder, for instance, can carry his work to considerable lengths at his own station, and the nutritional needs of a farm animal, which are much the same throughout the country, can be studied on the College Farm. On the other hand, with a majority of pests and a large number of plant diseases, it is impossible to arrange that there shall be an outbreak in any particular place or in any particular year, and the plant pathologist and entomologist more than most other agricultural specialists are compelled to treat the whole country-side as their experiment station. Thus, in agricultural entomology and phytopathology an early impetus was given to the development of what is usually known as the 'Advisory Service', although this term is perhaps too restrictive, for its originators described the 'main' duties of the adviser as consisting in 'the study of plant diseases in the field, in devising remedies, and in visiting places suffering severely from insect or fungus pests for the purpose of advising agriculturists'.

It was only after extensive field work had been carried out that the fundamental problems underlying the control of plant pests and diseases became apparent and led to research work of the type more usual at a Research Institute. The work on virus diseases, also described elsewhere in this book, is a case in point.

Secondly, the passing of the Destructive Insects and Pests Act of 1907 not only brought a realization of the need for the greater study of agricultural entomology and phytopathology, but it also had some influence on the organization which came into being to meet this need. The Orders issued under this Act could be neither framed

nor administered except under scientific advice, and it soon became apparent that for this purpose the Department required its own scientific staff. This led, in 1912, to my appointment as Entomologist to the Board of Agriculture, and subsequently—as the work extended—to the creation of the Plant Pathological Laboratory of the Ministry, now situated at Harpenden. Thus there came to be attached to a Government Department a small staff of scientists interested primarily in the application of agricultural entomology and phytopathology to administrative ends, and this again has tended to differentiate these two subjects, slightly but appreciably, from most of the other agricultural sciences. (For a parallel reason the study of animal diseases has also developed along rather special lines.)

The Development and Road Improvement Funds Acts and the Destructive Insects and Pests Acts have thus given shape to the present organization for dealing with plant pests and diseases, which may be summarized as consisting of:

(*a*) A considerable staff of entomological and phytopathological 'advisers' well distributed throughout the country.

(*b*) A staff of research workers not collected at any one research institute devoted primarily to phytopathology or entomology, but distributed among the other research stations of the country, some working on a crop basis, such as those at the horticultural stations, others on a subject basis, such as those at Rothamsted, or still others attached to academic departments—as, for instance, those studying insect physiology at the Imperial College.

(*c*) The staff of the Ministry's Phytopathological Laboratory, at Harpenden, who are associated not merely with the advisers and investigators falling under the two previous headings, but also with the Ministry's executive.

These three groups together may be looked on as the phytopathological service of the country, which has

grown up entirely during the present century, largely, in fact, since the War. A few instances of the achievements of the research and advisory sides of the organization will be given presently, but it may first be of interest to complete the historical picture by some reference to the legislative developments.

When the first series of Orders under the Destructive Insects and Pests Act of 1907 were issued, the control of pests and diseases by administrative means was to all intents and purposes a new departure, with little in the way of precedent to act as a guide to future work. These early Orders were influenced, however, by two factors that were prominent at the time. In the first place, the appearance of American Gooseberry Mildew, of Wart Disease of the potato, and an increasing fear of the introduction of new pests and diseases from overseas, prompted the desire that no additional troubles should be received from abroad and that an attempt should be made to eradicate those already here. Secondly, the United States of America, awaking to the losses caused by introduced insects and fungi, began to take stringent measures against plant imports from other countries. In order to meet these needs, two types of Order were issued, a general one dealing with a number of different pests and diseases, and special Orders, each aimed at the control or eradication of a single pest or disease. The former empowered the Board to take measures for the control of a schedule of notifiable 'pests', which consisted, in part, of those which this country did not want introduced or wished to eradicate, and, in part, of those which it was believed the U.S.A. would not want, no matter whether they were injurious here or not. Orders of the second type comprised a series dealing with American Gooseberry Mildew, Potato Wart Disease, and Silver Leaf of Fruit Trees. It would be tedious to trace here the vicissitudes of the work in its early stages, and it must suffice to recall that the attempt to eradicate American Gooseberry Mildew failed—a failure that was probably inevitable, but was naturally rendered more likely by lack

of knowledge from both the administrative and mycological aspects. The fight against Wart Disease, however, persisted, and its nature was largely influenced by the very important discovery of 'immune' (in fact, highly resistant) varieties of potato. The Silver Leaf Order, introduced at a time when the trouble seemed to be spreading seriously, failed to eradicate the disease, but it has proved useful, partly from the educational point of view and partly as a spur to the careless grower. The general Order, on the other hand, which required little from members of the public beyond the notification of pests and diseases which in most cases they could not recognize, remained largely as a weapon in reserve.

From 1914, the War interfered more and more with the administration of the Destructive Insects and Pests Acts, and no fundamental changes were possible until afterwards, when a complete overhaul and reconstruction of the then existing Orders was made. Of the diseases dealt with by special Orders, American Gooseberry Mildew was found to be controllable by lime-sulphur spraying, and attempts to eradicate it were abandoned. The Silver Leaf Order remained substantially the same, except for improvements in detail which had been rendered possible by research. The situation regarding Wart Disease was, however, more serious. Perhaps as a result of the war-time scarcity of seed potatoes, it had become much more widely spread, and the Department was faced with the discovery of a very large number of small infected areas, gardens and farms, notably but not exclusively in the industrial regions of the country—a number so large that it had become impossible to deal with each separately. Moreover, it had become abundantly clear that if the further spread of the disease was to be checked, the control of the distribution of potatoes, notably of seed potatoes, was essential. To meet these difficulties, the country was divided into two large areas, one with only isolated cases and indeed substantially free from the disease, and the other with very numerous infected areas and smaller units, but of course containing much land still 'clean'.

It was then provided that no seed potatoes for the 'clean' areas should be derived from the infected area in this country or from similar areas in Scotland or Ireland. It was also provided that the only potatoes to be allowed to leave the infected area should be those of ware size of an approved immune variety. Within the infected area, occupiers of infected land were permitted to plant only approved immunes, but those with clean land could plant susceptibles subject to the proviso previously mentioned that the produce must remain within the area. As an essential background to all this, the production and testing of new varieties of potatoes for immunity from Wart Disease achieved great importance and came under the aegis of the National Institute of Applied Botany in England; arrangements to the same end were made in the other countries of the United Kingdom, the final results—the issue of lists of 'approved immune' varieties—being co-ordinated by an Interdepartmental Committee.

The introduction of these measures, which admittedly caused some hardship to those with clean land in the infected area, was followed by an immediate drop in the number of new cases discovered, and a large area comprising the chief potato-growing districts of East Anglia has remained free to the present time, with the result *inter alia* that an export trade in potatoes has been retained. No measures that are practicable can, of course, prevent the slow spread of the disease, since it may be carried with soil on the roots of any plant, on implements and on boots; but with the steady production of 'immune' varieties of good quality, a time will doubtless come when it will be decided that the present Order has served its purpose.

Important as were the changes in the Wart Disease Order, those made in the 'general' Order were even farther-reaching. It has previously been mentioned that this Order dealt with a schedule of pests and diseases comprising both foreign species not yet established in the country and common resident species. So far as the former were concerned, it was an offence to introduce such species

into the country, but the Order provided no machinery for rendering the prohibition effective. Clearly the most likely, and indeed the usual, method by which new pests and diseases were introduced was through the medium of their host plants or the living produce of such plants, such as potato tubers or fruit, and an Order was issued, therefore, dealing with the importation of plants. The principle adopted in the Order was that certain categories of living plants and plant products should be imported only if accompanied by a health certificate granted by the official Phytopathological Service of the exporting country. The purpose of this certificate was not to ensure that the certified consignments should be absolutely free from pests and diseases—a manifest impossibility—but rather to secure that such consignments should be of a high standard of health. This in itself was felt to be a great gain, but the certificate system had the further important advantage that it provided a machinery whereby imported consignments could be followed up and treated in accordance with their liability to act as vectors of dangerous foreign species. A consignment of fruit trees from a western European country, for instance, was unlikely to introduce pests or diseases not already established in Great Britain, and all that was necessary in such a case was to keep out trees that were seriously diseased or so affected as to be a menace to any orchard in which they might be planted. With such imports, 'check' inspections to ensure that the standard of health implied by the certificate was maintained were sufficient. With plants from other *continents*, however, notably from countries with a temperate climate, entirely new species of pest or disease could be expected, species perhaps that had not even caused damage in their native country and would not be regarded as harmful by the inspectors there. With such consignments greater precautions were desirable, and it was arranged that they should be examined not only at the time of importation but also during their first season of growth, when the presence of pests and diseases could be more readily detected. Since the first Importation of Plants Order was

issued, a number of modifications have been introduced, but the general lines of the original Order have been retained. The chief modifications have consisted in the prohibition, either for part of the year or altogether, of the import (except under licence) of certain categories of plants and their products in cases where the certificate of health failed to provide the safeguard necessary. A second modification has consisted in the omission of a schedule of species regarded as specially dangerous, because of the impossibility of preparing any comprehensive list and because it was found that the inclusion of a short list led to misconceptions overseas, where the inspectors concentrated on the schedule and neglected all species outside it.

The importation of pests and diseases from abroad having been dealt with, consideration had then to be given to those within the country. Again, account had to be taken of two distinct categories—new invaders that might come in in spite of the Importation Order, and species that were firmly established. As to the former, it was clearly impossible to foresee which species might turn up, and all that was possible was to take general powers, so that immediate action would be taken on the detection of any foreigner. An order was issued, therefore, under which the Ministry has powers to deal with any 'non-indigenous' insect or disease. The powers under this Order are often sufficient for a campaign for eradicating an invader—e.g. under them many colonies of the Fluted Scale have been dealt with, and also one large outbreak of the Chrysanthemum Midge, which was effectively suppressed (a second outbreak is being fought at the time of writing); but the powers given by the Order may not be sufficiently precise to meet all contingencies, and then a special Order is issued, as was done with the Colorado Beetle in 1933–4. Here it became necessary not only to deal with a number of places in which isolated beetles were found, but also to take precautionary measures (notably by spraying) over a wide area. In circumstances such as this the powers of a general order are clearly insufficient and a special order

is needed. In principle, the Wart Disease Order mentioned previously also comes into the same category, for whatever may have been the origin of the disease, its behaviour and spread in this country have been similar to those of a new invader.

Finally, as to the species of insect or disease that are already common and widely distributed, the circumstances are entirely different, of course, from those attending the control of a newly arrived alien. Eradication, either from the country as a whole or even from restricted areas within it, is impossible, or if not impossible it is economically impracticable. For pests and diseases in this category, the broad principle adopted was that no one, either by distributing diseased plants or by negligence in carrying out measures of control, is entitled to render more difficult the task of others who wish to keep their crops healthy. The first Order of this type, issued not long after the War, was the Sale of Diseased Plants Order. At that period, as a result of war-time conditions, stocks of material for planting were low, and difficulties had been found in keeping such stocks in a reasonably healthy condition. On the other hand, the demand for planting material was great, with the result that diseased plants were often sent out with serious results to the new plantations then being made. The Sale of Diseased Plants Order was issued, therefore, prohibiting the sale of certain categories of plants if substantially affected by many of the more common diseases and pests. The moral effect of the Order was of greater importance, perhaps, than its penal clauses, but the latter were of value in preventing the sale by auction of unhealthy stock which no reputable nursery would ever have distributed—as, for instance, where a nursery was broken up for building-land and any stock left over sold by the purchaser of the land for what it would fetch. From time to time the scope of the Sales of Diseased Plants Order has been widened, but the principles underlying it have remained unchanged.

The sale of diseased or pest-affected plants having been dealt with, there remained only the problem of the negli-

gent grower, which may be exemplified by the case of the fruit-grower whose efforts to control a certain pest are nullified because his neighbour takes no steps to the same end. A difficulty of this sort is clearly of local importance only: it does not matter to the Cambridgeshire apple-grower, for instance, whether a Worcestershire grower controls Apple Capsid or not, but it is of great importance to the former if the occupier of an adjoining plantation refuses to take any measures. The case for action becomes even stronger when the efforts of a majority of growers in a given area are nullified by the negligence of a small minority, and where such conditions are shown to exist an Order can be issued which, in effect, requires the negligent minority to adopt ordinary routine measures of control for any pest or disease that is liable to spread from one property to another. Such an Order is administered by the Local Authority, but the agricultural industry of the area concerned has also to accept a considerable measure of responsibility for setting the machinery of the Order in motion, because it is realized that unless public opinion is solidly behind the administration, little good will result. From small beginnings (an Order confined to the control of the Black Currant Mite in Norfolk), this development under the Destructive Insects and Pests Acts has assumed considerable proportions, and public opinion would seem in favour of a more drastic rather than a more liberal type of Order.

This brief review has done no more than indicate the chief features of the administration of the Destructive Insects and Pests Acts as they have emerged during the past twenty-five years. Much has perforce been omitted and no reference whatever has been made to certain Orders, or even to the fact that during the period a third Destructive Insects and Pests Act—that of 1927—was passed. This Act, however, did no more than bring up to date the definitions in the earlier Acts (for instance, virus diseases were practically unknown when the 1907 Act was passed) and clear up certain administrative difficulties. The Orders throughout have followed the same general

principles, and the reader will be able to fit any that have not been mentioned into their proper place by reference to the following summary:

To deter the introduction of pests and diseases from overseas. The Importation of Plants Order, reinforced by a limited number of prohibitions.

To deal with dangerous invaders after introduction. The Destructive Insects and Pests Order, reinforced by special orders dealing with single pests or diseases.

To control common and widely distributed pests and diseases. The Sale of Diseased Plants Order and a large number of Local Orders.

Finally, it remains to cite instances of the achievements of the phytopathological service, a task complicated by the fact that results may be measured by different standards. The successful investigation of the basic facts of science may have greater importance, in the long run, than the solution of a problem with an immediate agricultural bearing: the former will perhaps appeal mainly to the scientist and the latter to the farmer. Then research is international, and discoveries in one country lead the way to new applications of those discoveries in others, and in few cases can the Service of any one country, still less can any one investigator, claim the full credit for the benefits that may accrue to agriculture or horticulture. Lastly, whether the achievements are 'fundamental' or immediately practical, it is essential to pick and choose, and within a short space it is impossible to do justice to all. Nevertheless, the attempt must be made, because in the long run any organization with a practical object must be judged by its practical achievements. Moreover, memories being short, the introduction of improved methods is forgotten in a few years, and such methods are subsequently regarded as commonplace routine. All that can be done here is to select a few of the more important crops and compare the present position in respect of the control of pests and diseases with that in 1913.

CEREALS. When I joined the Board of Agriculture in 1913, the cereal pests that were the subject of a majority

of inquiries were Wireworms, Leather Jackets, Wheat Bulb Fly, and Frit Fly.

As to *Wireworms*, some fundamental knowledge has been obtained, mainly of morphology and life-history, but the practical problems of controlling their attacks on cereals are not yet solved, and the advisory entomologist can but recommend palliatives, as he did thirty years ago.

Leather Jackets—which were formerly the bane of the farmer who practised certain rotations—can now be kept well in check by a poison bran bait, a discovery to which the investigators of several countries contributed, and which has been tested and popularized by advisory entomologists throughout Great Britain.

Wheat Bulb Fly at the time referred to above was a constant source of loss in the eastern counties and not infrequently elsewhere, notably farther north. The discovery that the fly lays its eggs on soil that is bare or relatively bare has enabled the farmer to plan his cropping so as to avoid the pest and has greatly reduced the cases in which serious injury is caused.

Frit Fly is not yet conquered, and in pre-War days it seemed to threaten the cultivation of oats as a major crop in the south of England. The substitution of winter oats in improved varieties for spring oats partially solved the problem: then the accurate determination of the stage of growth when spring oats were most susceptible to attack, and the sowing of such oats sufficiently early to enable the plant to pass this period before the main emergence of the Frit, carried the control a stage farther: finally the discovery that varieties of oat differed in their resistance to Frit, and that resistance or susceptibility were heritable characteristics, opened the way to plant breeding which is now in process of bringing forward new varieties in which good quality is combined with quite an appreciable resistance to the pest.

Fruit, with its rapidly increasing importance and also its high capital value per acre, has received the lion's share of the attention of the investigator and adviser, with results that can be appreciated only by one who was growing

fruit in the early years of the present century. In 1912, for instance, Aphides on top fruit were dealt with by the troublesome and ineffective method of spraying with thick lime wash; the cause of cracked and russeted apples (subsequently found to be due to the Apple Capsid) was then a mystery; no satisfactory control measures were known for the Apple Sawfly, for the Black Currant Mite, or for the Raspberry Beetle. Bordeaux Mixture was recognized as a spray against Apple Scab and lime sulphur was just coming into the picture, but the disease was everywhere widespread and the percentage of plantations in which it was properly controlled was very small. The comparison with the present time is very striking. Lime-wash has been displaced by tar distillates, not originally an English discovery but one that has led the way to important research work here on the whole question of winter washes, work that is still leading to improvements. Then the Apple Capsid was discovered, a partial control for it found in nicotine spraying, and this is now replaced by late spring spraying with a mineral oil. Successful control measures have been found for the Apple Sawfly, the Black Currant Mite, and the Raspberry Beetle. The prevention of Apple Scab is now a prime object with all apple growers, and although there has been little advance in the discovery of fungicides that are more efficient or more satisfactory than Bordeaux Mixture and lime sulphur, great strides have been made in the technique and time of applying them in commercial practice, mainly as a result of careful study of the disease in the orchard. As a result, the improvement in the quality of English apples in the past thirty years has been remarkable.

Glass-house Crops. No less outstanding have been the advances in the control of glass-house pests and diseases. Steam sterilization of soil has been brought to a fine art in respect of both technique and apparatus, with the resulting control of Root Knot Eelworm and other harmful soil organisms, such as those causing the Tomato Foot Rots. The destruction of the Greenhouse White Fly by hydrogen cyanide has been developed, an alterna-

tive fumigant found in tetrachlorethane, and finally its parasite, *Encarsia formosa*, has not only been discovered but has taken its place as a practical means of controlling the pest under commercial conditions. Again, the value of naphthalene as a fumigant has been found and also taken into the routine of the commercial grower, while the Tomato Moth, one of the first pests dealt with by those investigating glass-house troubles, is no longer a menace.

On the mycological side, the advances have been on a parallel scale, and in some ways, perhaps, of greater scientific appeal, for they have been found to consist less in the direct attack by means of chemicals than in the nice adjustment of the physiological conditions of the plants and of their environment, so as to prevent the development of injurious fungi rather than to destroy them after they have appeared. Again, the high value of the glass-house crop per unit area has given the investigator a latitude in the cost of control measures that is denied to those who are dealing with the pests and diseases of the farm.

FLOWER CROPS. Among flowers, daffodils have attracted more attention from the research worker and adviser than any other crop. Until about the year 1911 or 1912, the Large Narcissus Fly was perhaps the most serious pest with which the grower had to contend, but about that time the crops began to suffer from two troubles which at first were not properly diagnosed but one of which was subsequently proved to be due to the Stem and Bulb Eelworm. The outbreak of war, in 1914, and the general disturbance that ensued, at first distracted attention from this pest, but as soon as the situation was examined the trouble was found to be widely spread throughout the country, almost wherever daffodils are grown. Prior to this, it had been found that the Large Narcissus Fly could be controlled by immersing the bulbs in water at a temperature of 110° F. for an hour, and the further discovery was then made that by extending the period of treatment the eelworm could also be destroyed. From this simple statement, however, it should not be assumed

that the investigation needed to place the treatment on a commercial footing was equally simple. The lengthy treatment needed to destroy eelworms is only just tolerated by the bulbs, and damage immediately results if the treatment is not carried out when the bulb is in precisely the right condition—too early and too late applications being harmful. Quite apart from the principles of the treatment, difficulties arise when it is necessary to retain commercial quantities of bulbs at an almost fixed temperature (little latitude being permissible), and this has necessitated an independent investigation in which the physical conditions, notably those concerning the transmission of heat, in a 'system' consisting of bulbs in various containers immersed in water have been studied. From start to finish—if, indeed, the end has yet been reached—the investigation has occupied some twenty-five years, but it can confidently be claimed that, if success had not been achieved, daffodil-growing as a commercial proposition would have ceased.

The other part of the problem which proved so confusing in earlier days—that of Basal Rot—was finally elucidated some ten years ago, and now, provided that certain well-defined conditions of storage that predispose the bulbs to attack are avoided and fungicides are incorporated in the hot-water bath to prevent spread, there is no reason why this disease need longer be feared. Indeed, the advances made in this direction have already drawn attention away from eelworm and Basal Rot and towards Stripe and Root Rot, two major diseases for which a control is now being sought.

Another notable achievement in controlling the diseases of flower crops is instanced by Carnation Stem Rot, which became prominent after the War and caused much concern in many nurseries. This trouble was found to involve a number of distinct diseases, caused by species of *Verticillium* and *Fusarium*, and it has been overcome by improvements in the methods of cultivation.

Space does not permit of more extended reference, but the foregoing instances will give the reader some idea of the progress that has been made in the practical control

of plant pests and diseases in the past twenty-five years or so, and emphasis may be laid on the word 'practical' because in each case the commercial grower is in fact taking advantage of the discoveries in his daily work, which suggests that the research and advisory sections of what has earlier been described as the 'Phytopathological Service' are attaining the objects for which they were designed.

The achievements in the legislative sphere are of course much more difficult to estimate. Some of the results have already been indicated in describing the various types of Order—as, for instance, the eradication of certain foreign pests and the retention of a large area substantially free from Wart Disease. More often, however, success is shown by results that are negative in character; thus many foreign pests and diseases are intercepted in the administration of the Importation of Plants Order, but which of them would otherwise have established themselves is usually no more than a matter of opinion. On the other hand, there is no doubt that imported plants generally are now of a far higher standard of health than they were before the issue of the Order, and the same applies to home-grown plants since the Sale of Diseased Plants Order. Suggestive also is the fact that the agricultural and horticultural industries are tending to make greater use of the machinery of the Destructive Insects and Pests Acts. Without making exaggerated claims, therefore, it seems reasonable to deduce that the developments in the legislative sphere have been on the right lines, and with this conclusion the matter must be left.

LANDMARKS IN THE DEVELOPMENT OF SCIENTIFIC FRUIT-GROWING

By R. G. HATTON

'CANNOT we systematize the knowledge of the fine gardener? Cannot we reduce it to a science? Science is nothing more than systematic observation.' Sir Daniel Hall's plea 'for the recognition of horticulture itself as a science and as a subject for experimental study' was made in 1930 at the first official gathering of British Commonwealth horticulturists.

There is a great temptation to the horticulturist who is trying to survey the progress of this systematization in fruit-growing to trace back the developments at least to Thomas Andrew Knight. Many of the operations recommended in modern practice are minutely described much earlier in horticultural literature. However, these descriptions are so intermingled with fanciful lore that Knight, deliberately planning horticultural experiments, may rightly be regarded as the progenitor of fruit research in this country. Fortunately, more recent milestones have been provided by two other horticultural experimenters, Hall and Pickering—all three trained at the same College.

There can be no more appropriate and vivid description of fruit-growing at its best in 1911 than that in Hall and Russell's *Agriculture and Soils of Kent, Surrey and Sussex*—given in the very year which opened up new possibilities for the application of scientific method to agriculture. Kent had then approximately 40,000 acres of orchard and 25,000 acres of small fruit.

'Speaking generally, the Kentish fruit is grown on tilled land; apples are planted 20 feet apart, with plums equidistant between them, and nuts, gooseberries, or sometimes currants are planted in rows below. The apples are generally planted as standards or half-standards upon free stocks, with plums on the Mussel stock; the ground between is kept clean by digging and hoeing, rarely by horse labour. As the bush fruit gets old the apples and plums are often trimmed up to form standards; eventually the bushes are

removed and the land is laid down to grass, the plums being taken out in their turn as the apples grow large. Pure tillage orchards of large apples and plums are rarely seen, the old orchards having generally been laid down to grass. A few tillage orchards of dwarf apples, on the Paradise stock, are now to be seen, though not on the Ragstone soils of mid-Kent, where the dryness of the soil and the proximity of the rock obviate any necessity for a dwarfing stock.'

Such was the practice being widely developed in England up to the Great War.

'To any one of a scientific turn of mind the unsatisfactory basis on which the culture of fruit depends cannot fail to be apparent .... Even amongst the highest practical authorities there is hardly a single point in the cultivation of fruit on which unanimity of opinion prevails.' Thus commented *Nature* shortly after the establishment of the Woburn Experimental Farm in 1894. Pickering proceeded to plan controlled experiments on such routine practices as planting and pruning, manuring and grassing. The final account of these experiments appeared in Bedford and Pickering's *Science and Fruitgrowing* in 1919. To the latter's evident delight most of the findings, under Woburn conditions, and with the material and technique employed, ran directly counter to accepted practice.

After the initial furore thus created had died down, fruit-growers began to realize that many of their traditions needed qualification, and that a more exact knowledge of the principles underlying their routine was highly necessary. So, when the opportunity arrived, the fruit industry was amongst the first to clamour for the provision of facilities for research which would fulfil those 'highest ideals of investigation' envisaged by Pickering himself, where 'half a dozen branches of science . . . each with its laboratory and staff' would be working in a common establishment. Thus the National Fruit and Cider Institute, Long Ashton, founded in 1903, was granted, in 1911, the means to develop such a comprehensive team of investigators in the west, and became the Agricultural and Horticultural Research Station of the University of Bristol.

The John Innes Horticultural Institution, Merton,

founded through a private bequest, started work on the genetics of horticultural plants in 1911. Fruit-growers soon recognized that the investigations upon the self-sterility and self-fertility of fruit-trees would have a practical bearing upon the problems of pollination in the orchard. As the knowledge and experience of the geneticist and the plant breeder accumulated, these expectations have been fulfilled.

In 1912 East Malling Research Station was born of the South-Eastern Agricultural College, Wye, by the paternity of the fruit-growers of that area. Thanks to the broad outlook—a combination of science and practice—with which the College had been endowed, Wye had already stimulated the fruit-grower's interest, and, to meet his criticisms, founded a Station in the heart of the Kent fruit industry. The foresight in allowing for the development of more than one centre to study the reactions of long-lived horticultural plants under different climatic and soil conditions becomes obvious as the story of these investigations unfolds. While the problems at the different centres, and the methods of approach to them, have often been different, it becomes evident that the findings have largely been complementary and supplementary. As a result, the young fruit industry, in its rapid and widespread development, has been saved much time and expense in buying its experience.

The writer, in giving a brief account, from the pomologist's standpoint, of the progress in fruit-growing theory and practice in England during the past twenty-five years, has inevitably drawn information freely from the results of several Institutions. While he has deliberately interwoven the different threads which make up the whole fabric, he wishes to emphasize his indebtedness to all his colleagues in fruit research. He is particularly grateful to Professor B. T. P. Barker of Long Ashton for reading these pages and expressing general approval and to Mr. N. B. Bagenal of East Malling for valuable suggestions.

There are now some 80,000 acres of top fruit and 12,000 acres of small fruit in Kent alone. The total

effective area for England as a whole is approximately 310,000 acres. In little over twenty-five years many new areas have been developed for fruit culture, the mixed plantation of different kinds of top and small fruit has well-nigh disappeared, as has the hard and fast line once drawn between orchards under grass and tillage. Even the idea of the 'permanent' and 'filler' tree is rapidly passing and the 'standard' tree giving place to the bush form. To-day, almost every fruit crop is coming to be regarded as a special line. Not only has small fruit production become an industry in itself, but the apple, plum, pear, and cherry now rarely find themselves in the same orchard, even the culinary and dessert varieties being separated. Hand labour, except for skilled pruning, grafting, and spraying, is reduced to a minimum. Horses and sheep are now often entirely absent from the fruit farm, and their services, once reckoned to be essential, have rapidly been replaced by mechanical and chemical substitutes.

I. THE FRUIT-GROWER'S MATERIAL AND ITS STANDARDIZATION

The horticultural investigator's growing intimacy with commercial orchards made him realize the very uncertain results which fruit-growers were obtaining. Orchards often grew more or less vigorously and remuneratively than was expected, trees of a single variety did not all behave alike in their growth and cropping, the successes obtained with one planting of currants or raspberries could not be repeated with any certainty. Again, the Woburn investigations left the uncomfortable feeling that, for some unknown reason, Pickering's attempts to design and interpret exact experiments in the field had only very partially succeeded. Similarly, field experimentation, on a large scale, in the United States had yielded far too many inconclusive results. Yet a movement was on foot twenty-five years ago to improve and intensify fruit-growing in England and to give it the status of an industry, the new watchword of which was 'standardization'.

It was evident that neither the horticultural investi-

gator nor the commercial fruit-grower knew his plants. Their material was far from being standardized. There were long lists of varieties of small fruits from which to choose. Some sorts had been handed down from past generations and others had been recently introduced as novelties by nurserymen. Were the old varieties out of date or worn out? How could the new ones be distinguished and in what ways were they improvements? Did some varieties require different conditions from others?

As for his hard fruits, there were not only the claims of different varieties to be settled by the grower, but there were the complications of grafting and of rootstock. A few varieties were grown locally on their own roots, by breaking off branches or digging up suckers and replanting them. What then were the effects, if any, of grafting[1] and of the rootstocks? Tradition had much to say about the vigour of seedling 'Crab' rootstocks, and, recently, the 'Paradise stock', raised from layers and reputed to be dwarfing, had been reintroduced into England as a commercial proposition. Sometimes apples grafted on 'Paradise' had not enough vigour to make healthy bushes, sometimes they grew much too vigorously for the close planting recommended. Again, there were the seedling 'Free' rootstocks on which standard pear-trees were grafted and the quince rootstocks for dwarf bushes. The names of the rootstocks used for plums were too numerous and too inconsequent even to catalogue.

Here then were problems calling for immediate investigation by the Research Stations.

The small fruits, their varietal characteristics and health

The small-fruit work initially involved finding constant features of external morphology, by which one variety might surely be distinguished from another and by which a healthy individual could be separated from a diseased plant.

When methods of recognition peculiar to each class of

[1] Since no fundamental differences have been found to exist between grafting and budding, the former term is here used throughout to denote either method, though summer budding is the general practice in England.

fruit had been formulated, it was found that currants, raspberries, and loganberries had become badly intermixed and misnamed. Four distinct groups of black currant took the place of the original forty-six named sorts, some sixty varieties of raspberry were found to contain twice as many kinds, the names 'loganberry' and 'phenomenal berry' were interchangeable, and innumerable seedling variants were discovered.

Once the true varieties could be recognized, their performance was measured under different environmental conditions. It was not uncommon to find one variety giving four times the yield of another. It became obvious that varietal reactions to different climatic, soil, and even cultural practice were all-important, not only from the point of view of crop and market value, but because existing stocks had often seriously deteriorated from disease. For various reasons they had also become adulterated with a high percentage of sterile 'rogues' which, being often very vigorous, afforded tempting material to the unobservant for further vegetative multiplication.

This, however, was only a partial explanation of the grower's conviction that currants were 'reverting to the wild state' and cane fruits and strawberries 'running out' through long-continued vegetative propagation.

Once the characteristics of healthy cropping plants became recognizable, it was seen that many were showing abnormal symptoms of growth and foliage. Close study in the field made it possible to diagnose these symptoms, after taking into consideration varietal, climatic, and cultural factors. Careful grafting experiments proved that 'reversion' in black currants, 'mosaic' in raspberries, 'dwarf' in logans, and 'yellow edge' and 'crinkle' in strawberries were all transmissible diseases of the virus type. The spread of these diseases in the field was next studied. In some cases insect vectors have already been proved to transmit the disease. The 'big bud' mite carried 'reversion' and a satisfactory method of controlling this pest by lime-sulphur spraying at the most important period of its migration put an end to these menaces to black-currant

growing. Where migrant aphides prove to be the vectors, as in the strawberry, the control of such extraneous infection is more difficult.

In all cases, however, the main cause of the rapid spread of these diseases was the wholesale planting of progeny from diseased parents. It was essential to select healthy individual parents from which to rebuild and maintain healthy stocks, both for propagation and fruiting purposes.

In view of the peculiar nature of these diseases, which often manifest themselves only at certain periods of the year, and under particular climatic conditions, the propagation of such healthy material of necessity became a speciality. The diagnosis of these diseases, moreover, needs the trained eye, and, even then, the plants must be growing normally, free from any masking factors such as are likely to be found in the fruiting plantation.

The establishment and maintenance of healthy clones

Plans were therefore formulated for the establishment of cane and runner nurseries, as isolated as possible from likely sources of infection—such as cropping plantations and 'carrier' varieties—and adapted for easy inspection and efficient roguing.

Small experimental nurseries showed that it was possible in this way to maintain a high standard of vigorous plants substantially free from disease. From these clonal[1] 'nuclei', there grew up a series of commercial 'daughter' nurseries for raspberries and strawberries in various parts of the country. These have been regularly inspected and they have proved that, provided certain simple if strict rules of hygiene are adhered to, superior stocks of these fruits can be propagated economically on a commercial scale.

The methods of classifying and roguing black currants formed the basis of a Ministry of Agriculture certification scheme by which any grower can buy stock true to name and free from reversion. The drafting of certification schemes for other small fruits also is now overdue.

[1] A clone is a race propagated vegetatively from a single parent.

There has been a serious falling-off in the acreage under small fruit due to economic causes, which can best be met by a greatly increased production per acre. Now that restoration and maintenance of healthy 'strains' has been accomplished, and the search for and control of insect vectors is well under way, the road once again lies open for a study of the most economical methods of field culture.

The life-cycle of the strawberry plant

The great value of such investigations is illustrated by the life-cycle of the strawberry plant, which was carefully worked out in the south-west between 1924 and 1926. Some 1,200 runners were planted in early September and were subsequently lifted and examined in batches at three- to six-weekly intervals, over a two-year period, according to the state of growth. Detailed qualitative and quantitative observations were made of the strawberry's root and shoot growth.

After early September transplanting, very active root growth took place on the young runners and continued up to mid-December. The shoot growth was not at all proportional. Then followed a dormant period from December to March. The next phase was one of vigorous shoot growth, during which very few new primary roots were formed, though numerous lateral 'feeding' roots were produced on the original 'scaffold' roots. These characteristics obtained until after cropping, when very vigorous growth of both shoot and root took place. New 'crowns' and new primary roots 'arising from the lower portions of the new crown growth and from $\frac{1}{2}$ to $1\frac{1}{2}$ in. above the older roots', rapidly developed, as well as laterals from the old main roots.

The second year's observations confirmed the 'remarkable consistency of the sequence of events'. Though slight modifications due to seasonal, climatic, and soil differences were naturally expected, this picture was found to apply in general to such contrasting conditions as those existing in Norfolk and, later, in Kent.

Other series of runners were planted at different times

from autumn to spring. Some were allowed to fruit while others were deblossomed. The development of the individual runner plant, the number of crowns formed and the blossom–bud differentiation were also followed. Later the detailed life-history of every individual runner from certain healthy parents was followed under south-eastern conditions.

Interpreted in the light of the plant's root-shoot cycle, the conclusions reached from all these investigations immediately became intelligible, and the grower was given certain general principles to guide his choice of runners and of planting times, of fruiting or deblossoming young plants, and of appropriate and careful cultural operations during the critical, but often neglected, period subsequent to fruiting.

For many years past the average commercial crop of strawberries has been only from 15 to 25 cwt. per acre: the healthier stocks of plants now made available and cultivated in the light of these findings are producing commercial crops of 3–4 tons.

II. THE 'BUILD-UP' OF THE FRUIT-TREE

Propagation

Although it has long been realized that varieties of our tree fruits did not breed true from seed, there has been no general attempt to establish them on their own roots. While tradition has pointed out the exceptional instances in which varieties exhibiting 'burr-knots' (aerial roots) on their stems and those prone to send up suckers from their roots could be multiplied by these means, the general practice of grafting on to rootstocks has always been recommended.

The Paradise, Quince, Mussel and Brussel Plums were regarded almost as a class apart owing to the ease with which they rooted when 'earthed up', otherwise nearly all varieties were grafted upon rootstocks of seedling origin.

The physiologist in company with the propagator, therefore, set out on a voyage of discovery into the realm

of nursery practice. Their most far-reaching find was the beneficial effect of 'etiolation' upon the base of the shoot from which it was desired to encourage adventitious rooting. This 'blanching' can be effected by laying down the parent plant along the ground and covering it over before the buds break. The bases of new growths pushing their way through the soil are thus etiolated. By adaptations of this method, vegetative propagation has been extended to a number of kinds and varieties of fruit hitherto considered 'difficult' or 'impossible' subjects. Again, root-cuttings, hard and soft wood cuttings, 'stooling' and earthing-up, and layering were all studied in relation to kind, variety, appropriate season, medium, and environment. Some varieties proved more adaptable than others to particular methods and conditions of multiplication.

Finally, the American method of grafting directly on to one-year seedling roots or root-pieces has been explored with the object of inducing the scion variety so 'nursed', and planted deeply, to establish itself on its own roots. While examination in an irrigated Canadian nursery revealed that, at one year old, 100 per cent. of many varieties had already produced scion roots, in England this could only be effected with a limited number of varieties, of which Bramley's Seedling proved to be one.

Having thus broadened the basis and simplified the processes of vegetative propagation, the investigator was in a better position both to examine the various groups of rootstock in commercial use and to measure their influence upon the scion.

In horticultural tradition, fruit-tree rootstocks fell into two main groups, those of seedling origin (often called 'free' stocks), which were *ipso facto* deep-rooted and therefore imparted vigour and longevity to the scion, and those propagated by vegetative methods, which were *ipso facto* shallow-rooted and therefore induced a dwarfed habit and short life.

The Research Stations agreed to examine both groups of rootstock, with a view to formulating some botanical and horticultural classification, as a preliminary to evaluating

and, if possible, to determining their influence upon the scion.

'Free' or seedling rootstocks

Methods of classification. While investigation of the vegetatively produced rootstocks presupposes working with homogeneous material, the difficulties of conducting exact experiments with rootstocks of seedling origin are obvious. Owing to the complicated nature of the inheritance of our common deciduous fruits, no two individual seedlings are identical, neither can they be reproduced by sexual methods with any degree of certainty. Strictly speaking, the unit for experimentation is therefore one, and it is never possible to say whether that individual is behaving normally under any particular set of environmental conditions. It was decided, however, to explore different methods of classifying seedling rootstocks by their characteristic types of root-system or of growth and foliage.

The root-systems of a representative collection of seedling apple rootstocks were carefully examined and very distinct types of root development observed and described. One or more individuals, representative of each of 9 'root' groups, were selected and multiplied vegetatively for grafting tests, in the hope that some definite root characteristics might be correlated with some visible effects on the scion. Incidentally, it was found in general that these vegetative clones resembled one another more closely in root type than the original seedling parents. This unique range of vegetatively raised 'free' rootstocks, after trials on several soils and with different scions, has not revealed any such correlation, though it has demonstrated that a wide range of performance in the scion is to be expected upon rootstocks of such heterogeneous origin.

Attempts were made to classify seedling pear, plum, and cherry rootstocks from their growth and leaf characteristics. These indicated the recurrence of very distinct 'types'. The vegetative propagation of a representative range of clones within each group was undertaken. The

trees grafted on these clones revealed, again, a wide range of behaviour within any one botanically similar group.

In addition to the great variability of such populations in rooting readily and to the usual range of growth and vigour in the scion, many of the plum rootstock clones demonstrated a new and unexpected phenomenon. 'Incompatibility', i.e. the failure of the rootstock and the scion to form a lasting vegetative union after grafting, was shown to be an additional cause for uncertainty in the behaviour of seedling rootstocks. Cases of complete and partial 'incompatibility' were also found in some of the 'free' apple and pear rootstocks.

Thus, by the only practicable methods available to the investigator, a wide range of performance—in ease of rooting and subsequent root development, in manifestations of compatibility and 'incompatibility', and in effect on the vigour and cropping of the scion—was found to exist in these populations of seedling rootstocks. None of the methods explored for classifying such material, nor even a rigorous grading of the seedlings according to size, could have eliminated these inherent differences.

The criticism may be advanced, with some justice, that the use of vegetative propagation in these investigations begs the whole question of the inherent virtue sometimes claimed for a rootstock propagated by sexual methods. There has been no orchard experiment deliberately designed to elucidate the relative merits and uniformity of trees grafted both upon seedling and clonal rootstocks. The behaviour of trees in the nursery presents only one aspect of uniformity, i.e. growth. To plan such a field experiment would involve large numbers of trees to ensure embracing a representative sample of seedlings. The range of performance which exists in such populations has already been demonstrated by far simpler means.

A natural grading in commercial practice

True, these extremes of behaviour are only infrequently seen in commercial orchards on seedling rootstocks, the

majority of which undoubtedly produce vigorous growing trees, though, where any factors tending to limit optimum growth conditions prevail, striking irregularity is often noticeable. It must be remembered, however, that a severe grading of such trees—on the basis of vigour and 'incompatibility'—has already taken place in the normal commercial routine. The seedling rootstocks have first been graded into sizes, nature has already eliminated the worst 'incompatibilities', and the nurserymen deliberately discarded the less thrifty trees. Thus the most glaring manifestations of variability disappear.

Selection of parents for sources of seed

As an outcome of the general realization of this variability, and of a better appreciation of the genetic factors involved, workers in different countries are now seeking for appropriate parents which will give 'true lines' of seed, with the majority of the population possessing certain known attributes, such, for instance, as hardiness to winter injury or resistance to specific diseases. Progress towards a greater measure of uniformity in certain characteristics has undoubtedly been made, and such seed is being officially distributed to nurserymen in Canada.

'Root grafting' and 'Scion-rooting'

The elimination of the varying influence of seedling rootstocks has been effected in two other ways. First, it has been demonstrated that, when certain varieties are grafted directly upon *one-year-old* seedling roots, these scions predominantly influence the root-system, imprinting thereon easily recognizable characteristics. In fact, the scion variety 'takes command' of the seedling roots and renders them uniform, with a root morphology approximating to that of the scion itself. Apparently this effect has not yet been obtained on roots older than one year, and the commercial scion varieties which clearly manifest this influence upon the root are uncommon. Nevertheless, a most interesting aspect of rootstock–scion interrelationship has been revealed for further investigation.

Secondly, as a result of the common practice in Canada and U.S.A. of 'bench-grafting' young trees direct on to piece-roots in winter, to meet the special economic and climatic conditions, there is evidence that, where soil factors have been favourable, large acreages of such 'bench-grafted' trees have established themselves on their own roots and are growing very vigorously, and apparently uniformly. Despite this, a number of fruit-growing areas in America have now seriously turned their attention to the commercial use of clonal rootstocks, for reasons which will be mentioned later.

A study, in England, of the behaviour of apple- and pear-trees which have established themselves on their own roots, as a result of the union between the scion and dwarfing rootstocks being planted too near soil level, has brought to light serious disadvantages of scion-rooted trees. In addition to the loss of control of tree size, the scions tend to grow very vigorously and fall off in cropping. On pears, the very vigorous and erect growth of these sterile trees becomes readily infested by Scab and Canker, and the fruit-grower has come to recognize the cause of his all too frequent 'passenger' trees.

The vegetatively raised rootstocks

The investigation of this aspect of the problem at the outset resolved itself into the collection, botanical description, and subsequent re-establishment of clonal races of the named varieties of 'Paradise' apple, quince, and various plum rootstocks in commercial use. Some of the experiments already described revealed a number of individual seedlings which multiplied readily by vegetative means and which also exhibited other promising characteristics. Such new varieties were tested side by side with those in commercial use.

Description and classification

Examination of commercial samples showed that the varieties had often become intermixed and their nomenclature badly confused. For instance, at the outset at least

nine distinct varieties of the 'Paradise' stock were found to be in common use in Europe, and a further seven were in process of introduction. Since then eight further 'Paradise' apple stocks have been found in commercial nurseries.

Five variations of the 'Mussel' plum stock were found. The Brussel, the only clonal plum stock then in wide circulation, though true to variety, was called by various names.

The varieties of quince proved much more difficult to separate on morphological characters, though eventually four rootstocks were described as being readily distinguishable, and a number of 'sub-types' were isolated. To avoid all possibility of misunderstanding, and until an agreed nomenclature could be adopted, the rootstock clones were generally referred to under an identification number or letter.

In due course, families of all these layered rootstocks, and of new introductions, were raised, and the first series of grafts was made in normal European fashion upon the stems of the apple rootstocks in 1917–18.

Measuring rootstock 'influence'

The behaviour of four scion varieties—Bramley's Seedling, Lane's Prince Albert, Worcester Pearmain, and Cox's Orange Pippin—on sixteen varieties of supposedly dwarfing 'Paradise' rootstocks has now been observed for eighteen years.

At first a complete measurement of the chief manifestations of rootstock influence upon growth, health, and cropping was made on some 1,500 individual apple-trees on one soil alone in the south-east. As the trees became older, the number of observations had inevitably to be reduced, but a fairly complete picture of the growth and fruiting habit of the trees has been maintained.

Grouping of the 'Paradise' rootstocks

Differences in the effect of rootstock upon the scion appeared in size and sturdiness of tree and in axillary fruit-bud formation, even at one year old. These early

indications were so strikingly confirmed by the behaviour of the young trees in the orchard that, in order to try and clarify the position for the fruit-grower, an attempt was made to group these 'Paradise' rootstocks according to their growth and the number of fruit buds per metre of wood. Four distinct groups—very dwarfing, semi-dwarfing, vigorous, and very vigorous—were then indicated.

After eighteen years of close observation it is clear that this grouping needs some qualification. While the 'very dwarf' rootstocks—Nos. VIII and IX—have invariably produced a relatively marked dwarfing effect upon all scion varieties tested under all conditions, and the 'very vigorous' rootstocks Nos. XII and XVI have never failed to produce trees of exceptional size, considerable differences in the behaviour of trees on rootstocks Nos. II and I—originally grouped as 'semi-dwarf' and 'vigorous'—have now been found to occur with different scion varieties, and to some extent under different environmental conditions. Again, trees on certain rootstocks—such as Nos. IV and VII—in the early years grew vigorously and cropped heavily at one and the same time. Eventually trees on these rootstocks formed a distinct 'semi-dwarf' group.

Some rootstock effects

At eighteen years old none of the trees shows any signs of deterioration, but although they were all planted 15 feet square—an unheard-of distance for trees on the 'Paradise' and on the Ragstone formation—many have been removed owing to overcrowding. At sixteen years old, scions on very vigorous rootstocks were four and five times as heavy as on the very dwarfing rootstocks. The trees of one variety on No. IX had actually produced 7·5 times their own weight of fruit in fourteen years, while the very vigorous trees on No. XII were about equal in weight of wood and crop. Such differences in size of tree and period and amount of cropping—which are matters of extreme importance in the economic planning of an

orchard—have now been proved to obtain, with some modifications, under varied types of soil and climate, in many countries. In addition, it is apparent that the rootstock affects the tree in many less obvious though no less important ways. The leaf area, the types of growth, fruit-bud formation and position, the percentage of blossom setting and the time of its opening, fruit colour and ripening, storage quality and resistance to rots, chemical composition of shoot and fruit, resistance and susceptibility to certain diseases and physiological troubles (such as 'leaf scorch') have all been significantly affected.

Experiments now in progress suggest that an even wider range of rootstock 'performance' can be attained by the breeding and selection of new varieties of rootstock.

Vegetative 'incompatibilities' in pears and plums

Rootstock–scion relations have proved to be equally important in other deciduous fruits. Similar effects upon the range of vigour and cropping of plums and pears have been demonstrated. While the phenomenon of 'incompatibility' has appeared only rarely in apples, it has been of frequent occurrence with many combinations of pear on quince, and plum and peach on rootstocks of several species of *Prunus*. These 'incompatibilities'—and certain definite 'partialities'—between rootstock and scion are not explainable on grounds of inter-specific grafting, nor has it been possible to correlate them with a difference in chromosome number. In view of its practical importance to the nurseryman and of its bearing upon the fundamental principles of rootstock–scion relationships, considerable attention has been paid to studying this 'incompatibility'. While the various degrees and symptoms have been carefully described, and at least some of the immediate causes of disintegration discovered, the underlying physiological reasons have yet to be unravelled. Certain functional differences, however, between incompatible rootstock and scion combinations—such as differences in growth-rate and cambial activities—frequently appear to be contributory causes.

The search for the sources and limits of rootstock influence

Investigators have been endeavouring to explain, in physiological and chemical terms, these far-reaching influences upon the scion which the horticulturist has demonstrated, through his classification of this haphazard selection of rootstocks, to exist. An understanding of the basic principles of rootstock–scion relationships—whether qualitative, or quantitative, or both—might prove an invaluable key to interpreting many complex problems of tree performance.

The observation that certain scion varieties took control of the one-year-old seedling roots upon which they were grafted direct, led to the concept that rootstock influence must lie in the piece of rootstock stem eliminated by this method of grafting. Numerous experiments have shown that the interposition of pieces of stem betwixt the roots and the top scion produces significant effects upon both portions. The longer the piece of intermediate stem, the greater is likely to be the influence. Trees directly grafted and maintained upon root pieces of clonal rootstocks have also shown the typical influences associated with the rootstocks when stem-grafted.

It is evident, then, that rootstock 'influence' lies both in the stem and in the root portions, though some experiments suggest that the latter is the more potent. However, the importance of the influence of the stem piece must not be ignored where in nursery practice trees are 'double-grafted' for various reasons.

Studies of the structure of the stem and root portions, both above and below ground, have revealed large differences in the anatomical characters of different rootstocks. The relative percentage of the elements of the wood varies considerably in different rootstocks and bears a marked correlation with the vigour of the scion variety grafted thereon. So far, scion variety has not markedly modified these characteristics. A still more striking correlation has been found between the relative amount of 'bark' to wood of the rootstock and the vigour of the

scion. What part these differences play in rootstock 'influence' remains to be proved. They have already proved useful as an aid to the identification of commercial samples, and, if these correlations can be established in greater detail, they would afford a valuable aid in the selection of desirable new rootstocks.

The commercial application

Meanwhile, nurserymen in this country have not been slow to establish from this nucleus clonal stoolbeds on a scale which now renders them largely independent of Continental exigencies. Many others have followed suit, and actually these clonal rootstocks are under trial in some thirty-four different countries. In parts of Canada and the United States it is now realized that trees bench-grafted on to seedling roots—and probably scion-rooted—have proved too large for the proper application of modern cultural requirements. It is admitted that the necessary control of the tree has not been attainable by adaptations of management, and this is now being sought by the introduction of previously tested clonal rootstocks from Europe.

In Australia, New Zealand, and South Africa, it is now appreciated that apple-trees upon the Woolly Aphis immune Northern Spy rootstock are often too stunted and short-lived under many conditions, and a search for more vigorous immune forms is in progress. The widely recognized need for greater attention to the 'build-up' of the fruit-tree has encouraged the deliberate breeding of new rootstocks combining a number of desirable qualities. Already some 800, immune to Woolly Aphis, are under test, and some have proved definitely more vigorous than Northern Spy.

The experimental error in field investigations

The recording of measurements and weights upon numbers of individual plants of clonal origin over a considerable period has been justified on other grounds. It has not only presented the horticulturist with a picture of the visible interactions between different parts of his

plant and between them and external factors, it has also made it possible for him to estimate the degree of variability inherent in his material.

It is at last possible to assess how much of the observed differences in behaviour are due to chance and how much can be attributed to the different treatments which are undergoing comparison.

The pomologist's experimental material cannot be harvested annually and resown. Again, total crop is not the only object in view. The plant is there for a comparatively long life, which is influenced by the 'hang-over' from year to year of climatic and other factors. This material must be planted at considerable distances apart and it is necessarily subjected to a number of manipulations and spraying treatments. Thus the effects of soil variations, of wind and shelter, of the 'evening-up' through routine operations, and of the disturbances caused by disease, have all to be taken into consideration and their relative influence upon the plant's behaviour assessed. It is not to be wondered at that little reliable evidence could be deduced from field trials with fruit plants until the limits of variation within clonal races growing upon their own roots, and within the more complex grafted fruit-tree, had been measured.

Analyses of the data recorded have now made it possible to apply statistical methods with greater precision in the orchard. The planning of experimental fruit plots has been studied in relation both to the requirements of the mathematician and to the necessities of the horticulturist. The 'Randomized Block' and the 'Latin Square' have been adopted, with modifications, for the experimental orchard. It has been possible, as a result, to reduce the minimum number of experimental plants and to detect finer differences in their behaviour.

III. THE EFFECTS OF EXTERNAL AND INTERNAL FACTORS UPON THE TREE

The first essentials for a satisfactory fruit-tree are a framework of a size and shape suited to the methods of

culture envisaged, and a regular and adequate succession of fruit-buds.

Apart from the belief that some rootstocks produced more dwarfing trees than others, the grower had to rely mainly upon the arts of branch- and root-pruning, of training, and of ringing to control growth and cropping. So long as he could give plenty of attention and labour to the individual tree he managed to maintain a satisfactory balance, but when these operations had to be applied in commercial plantations it became obvious that root-pruning was no longer possible and that the principles underlying branch-pruning and ringing needed elucidation.

During the past twenty-five years investigators have paid much attention to the details of growth and fruit-bud production and to the reaction of the tree both to manipulations and other external factors. The relationships of each part of the tree to the others, and their possible influence on its internal conditions, have been closely watched.

While the ultimate aim of the physiologists has been to establish the general principles governing the relative value of this or that manipulative method, yet they have largely directed their work towards the solution of the fruit-grower's immediate problems. At the same time, detailed studies of the growth-cycle of the shoot and its buds, of different types of shoot, of fruit-bud differentiation and the factors governing it, of leaf area in relation to fruit-bud formation, and of the interrelationship of leaves, shoots, stems, and roots are slowly revealing the complex mechanism of the fruit plant.

Pruning

The climatic conditions of the south-east proved eminently suitable for an analysis of the response of apple- and pear-trees to various winter pruning treatments in the field. This showed the importance of the treatment of the main extension or 'leader' growths in relation to the number, position, quality, and setting of fruit buds. 'Leader' tipping and lateral growth or 'spur' pruning

were considered in the light of the individual responses of some fifteen varieties of apple at different stages of their development. As a result, rule-of-thumb methods of hard pruning and the alternative of neglect have been replaced by an appreciation of the needs of each tree in the light of its ascertained response to different treatments. Trees were grouped according to their varietal characteristics, and recommendations were made for the treatment of each group according to the age, vigour, and the purpose for which the tree was intended. More recently, problems of the maintenance of 'vigour' and fruit-size in mature trees, and of the effect of pruning to counteract the 'biennial habit', have come into prominence. In consequence, the processes of branch- and spur- thinning, 'dehorning', and local spur shortening have been evaluated in relation to the tree's past performance and present condition.

Causes of fruit-bud formation—effect of ringing and cultural operations

As a consequence of the particular climatic conditions of the south-west, a series of investigations of the ultimate causes of fruit-bud formation was initiated. This started with a detailed study of the 'normal' growth of apple- and pear-shoots, of the strength and position of buds, and of the varietal factor. In order to explain the observed phenomena certain hypotheses such as the sap-concentration factor, the Loeb 'effect', and the carbohydrate–nitrogen ratio were next examined. These intensive studies were supplemented by experiments in ringing, notching, and partial defoliation. It was realized that these simple manipulations, like pruning, must vitally affect the internal conditions of the tree. They might be causing 'a cessation in the downward translocation of plant food'. They might also be disturbing the water relations in the tree, or even the upward or downward movement of any root- or shoot-forming substances. The direct result of these investigations was to give more precise information about the optimum times and methods of ringing and notching

and about their safe limits for appropriate purposes. These methods proved equally potent in bringing into blossom-formation the over-vigorous trees growing on the strong silts of the Wisbech area, and the trees exhibiting a too extended elongation-growth period, encouraged by the high rainfall in the west.

Further analysis of the factors governing fruit-bud formation in the apple emphasized the importance of the previous summer's rainfall in affecting the tree's internal condition—i.e. the presence of organic food reserves—and the date on which extension-growth ceased. Individual seasonal growth-curves were plotted, both for varieties and rootstocks, which could be correlated with certain peculiarities in fruit-bud formation. It was particularly suggestive to find that trees on No. IX rootstock, which induces precocity in fruit-bud formation, 'showed a much more rapid, and in some cases an earlier, falling off in the growth-rate of the leader shoots'.

A complete census of the different categories of growths—primary and secondary, bearing and non-bearing—has also been made in the south-east on a number of Cox's Orange Pippin trees growing upon different rootstocks. This complementary evidence showed significant differences in the relative numbers of each category of growth upon different rootstocks and in different seasons. It also confirmed, under widely different climatic conditions from those in the west, the abnormal growth-curve of trees on No. IX rootstock.

After a survey of other conditions in the west, it was ultimately concluded that those factors which tended to check excessive elongation-growth and to induce its cessation comparatively early in the season were conducive to fruit-bud formation. The possibilities of adapting cultural methods to bring about this desired effect were consequently investigated. Largely as a result, 'partial cultivation', 'weeds', 'cover crops', and even 'grass' have been adopted as alternative methods of controlling tree performance, as seasonal circumstances and tree condition require. While 'rootstock influence' has by no means

been eliminated by any of these practices, many similar 'effects' can be obtained thereby.

Flower-bud differentiation and the seasonal cycles in the tree

Studies of the time of flower-bud differentiation of apples have shown that this begins, both in the south-west and the south-east, during the latter part of June, in buds on spurs and one- and two-year-old wood.

It is all-important to know what are the optimum external and internal conditions at this period for a regular supply of healthy fruit buds. Chemists are rapidly accumulating a wealth of facts about the seasonal cycles of changes in the amounts and proportions of carbohydrates, nitrogenous materials, and the elements in the ash in various parts of the tree. They are trying to correlate these with equally marked changes observed in the annual cycle of growth, but methods by which this 'chemical routine' can be adjusted are not yet obvious. In fact, these seasonal cycles are reported to appear very uniform, and only slight changes have so far been found associated with different manurial or cultural treatments. Rootstocks have been found to influence the chemical compositions of terminal shoots of the scion, as well as its growth cycle. Generally, the more vigorous rootstocks induced a high potash–nitrogen ratio, whilst the dwarfing No. IX accelerated the accumulation of certain materials by nearly a month.

In some countries, applications of nitrogen at appropriate times have been claimed to influence fruit-bud differentiation, but so far no clear evidence is available under English climatic conditions.

Leaf relations

Pickering, recognizing the importance of the leaf relations, used leaf-measurements for the evaluation of various cultural treatments upon the tree's vigour. Several workers have tried to develop the method and to obtain more representative samples, but the different types of leaves and the difficulty of handling them *in situ* have hindered progress in this important line. However, it has

been proved that a number of internal and external factors—such as rootstock, pruning, manuring, blossoming, and fruiting—reflect themselves in leaf size and total leaf area.

The relationship between leaf area and fruit-bud formation has been graphically shown in a two-year study of the leaf areas of two biennially bearing trees. The same average number of leaves per spur was found on both trees in the 'on' year, and similarly in their 'off' year, though they were fruiting in alternate years. 'The number of spur leaves carried per spur is 50 per cent. greater in the "off" year than in the "on" year. The areas of these leaves, however, are 300 and 400 per cent. greater for trees A and B in their "off" years than in their "on" years.' While this was due partly to the number of leaves, it was due mainly to their increased size. Similar studies have been made upon the size and position of leaves upon trees on different rootstocks (V and IX). There was a greater leaf area per unit length of stem and a higher proportion of spur leaves upon the 'precocious' No. IX.

Factors affecting flowers and fruit set

The fate of the blossom which has formed—regardless of the horticulturists' tentative efforts to control its quantity and quality—is being studied in detail.

Evidence is accumulating to show that there is a basis for the fruit-growers' classification of 'strong' and 'weak' blossom, and that this outward manifestation—presumably of some nutritional factor—may vitally affect both the percentage and the position of the flowers which remain to grow into mature fruit. Close observation has also led to a greater discrimination in assigning to climatic and other environmental factors the failure of flowers to set fruit and to survive the 'June drop'.

As orchards have become more specialized to meet market requirements and modern cultural methods, so the number of varieties grown together has rapidly decreased and the problems of the failure of trees to set remunerative crops have increased.

Sterility and its causes

Fortunately, the work of the John Innes Institution has reached a stage within recent years when its application became a practical possibility and a vital necessity. In 1911 evidence was produced to show that climatic and cultural factors were by no means the only important ones in blossom-setting. Fruit-growers began to realize that there was often something necessary in addition to the provision of more than one variety blossoming contemporaneously, and of conditions ensuring the presence of insects. The vague ideas that certain varieties were self-sterile and even required an 'appropriate mate' which then prevailed have to-day been developed into an imposing body of precise information.

The plant breeder, under conditions which assured the control of other factors, proved that certain varieties would not set fruit if 'selfed' with their own pollen, and that certain crosses also failed. The causes of these phenomena have been gradually revealed. The relative importance to the fruit-grower of 'incompatibility'—when the pollen will not grow down the style, of morphological sterility—where abortive organs are found, and of generational sterility—where the germ-cells of pollen or ovules are defective—have been explained.

Thus one of the most important group of causes of lack of fertility in fruit-trees has been demonstrated, and definite guidance provided for the fruit-grower.

The knowledge obtained with regard to 'incompatibility' is most important to the cherry- and plum-grower. Some seventy varieties of sweet cherry have already been under experiment. Eleven groups have been formed, within any one of which the varieties are non-compatible. All these groups have also been found to be inter-compatible, provided that the blossoming season overlaps sufficiently.

The grower now knows that all his sweet cherry varieties are self-incompatible, that cross-incompatibility is common and that, where this exists, it is reciprocal for

both varieties. In the light of this information and of the relative times of blossoming of different varieties, tables of effective cross-pollinators have been compiled. Further, while most sour cherries will cross-pollinate sweet cherries satisfactorily, the reverse is not true.

Similar facts about some fifty-two varieties of plum (*P. domestica*) have been ascertained. Though the results are less simple, owing to the plum's complicated inheritance, it is now possible to guide the plum-grower in his choice of varieties and to rectify some of his past failures.

The reasons for these phenomena in the cherry and plum are accounted for by the cytologist in his studies of the number of chromosomes in the cell nucleus—all our top fruits being proved to be polyploids. When the position with regard to the apple is considered, the lesson from his work becomes most obvious. Apple and pear varieties can be placed in two groups—diploids and triploids—according to their chromosome constitution. It has been clearly stated that 'triploids are less fertile than diploids when fertilized with the pollen from diploids, and still less fertile with pollen from other triploids. Further, pollen from the triploids gives low fertilization on the diploids.' When it is realized that Bramley's Seedling—the most widely planted commercial apple—is a triploid, the significance of these findings becomes apparent. In order to pollinate his Bramley's Seedling, the fruit-grower must provide a suitable diploid variety with a second diploid to ensure efficient pollination of the first.

Thirty-four varieties of pear have been examined, of which no less than seven are of the same triploid constitution, though the general position for pears has not yet been so fully explored.

Work on the compatibility of apple varieties has so far revealed only two which are entirely incompatible, but there is apparently a wide range in the degree of self-compatibility. Cox's Orange Pippin on 'selfing' has set only 0·76 per cent. fruits, yet from various crosses it has averaged 7·1 per cent. While this is an exceptional case, the fruit-grower will do well to remember that the average

fertility ratio of apples on selfing has been found to be 2·6 per cent. as against 10·9 from crossing. Again, there exists considerable cross-incompatibility between Cox's Orange Pippin and some of the other commercial dessert apples, such as Ellison's Orange and Laxton's Superb with which it is so often interplanted. It is suggestive that Cox's Orange Pippin is one parent of these varieties.

The practical importance of morphological sterility is shown by the need for interplanting with suitable staminate varieties a strawberry such as Tardive de Léopold in which the stamens are almost completely lacking.

This knowledge is being used to benefit the fruit industry in many other ways, chiefly by forming a scientific basis upon which the fruit-breeder can build.

IV. THE ROOTS OF THE FRUIT-TREE, THEIR REACTION TO ENVIRONMENT, AND THE LIFE-CYCLE OF THE ABSORBING ROOT-SYSTEM

The interrelationship between the stem and roots has been another subject of investigation in studying the external and internal factors influencing the tree's performance. The ratio of stem to root is seen to remain remarkably constant under any given environmental conditions, irrespective of rootstock or size of tree. It has been found that 'the new matter added in growth is distributed between stem and root in fixed proportions' and that, whilst stem pruning reduced the total amount of matter added, it did not alter the proportional distribution.

Though the rate of growth of different scions and rootstocks often differs, they find a common value when in combination. It may be that some scions or rootstocks are especially 'potent' and impose their growth-rate upon the partner. It is significant that an examination of some of the most striking cases of 'incompatibility' between scion and rootstock showed that the growth-rates differed very widely.

The roots of plants have been described as 'the mirror image of the shoot'. In order to see how far such a con-

ception applied to the fruit plant, investigations have been concentrated upon the root-system.

Spread and depth of roots

Some thirty years ago, American workers demonstrated, by the 'washing-out' method of excavation, that the roots of fruit-trees on seedling stocks spread laterally far beyond the branches and penetrated vertically downwards to a depth of 9 or 10 ft. according to soil moisture factors. This work, too, exploded the myth that a tap-root was necessarily or even generally present on a mature seedling root-system. Similar data from isolated excavations in this and other countries, and the growing realization of the importance of soil profiles suggested that the time was ripe for an intensive study of the behaviour of the tree's roots, which afford both its anchorage and its means of absorbing water and minerals in solution. Such a study should be especially valuable in view of the intensive interplanting of small fruits, and of the close planting of trees on 'Paradise' rootstocks.

Root-systems were often classed as 'vigorous' or 'restricted', 'deep' or 'shallow', 'fibrous' or 'fangy', with a tap-root present or absent, and upon such a grouping has been based in the past their reputed influence upon the scion for vigour or dwarfingness, for long or short life, and for different degrees of productiveness. Now that trees worked on clonal rootstocks of known morphological and horticultural characteristics were available, more precise investigations were possible.

A number of ten- and eleven-year-old apple-trees of a single variety were selected for excavation in their entirety. The trees were on clonal rootstocks representing a wide range of vigour and precocity, on three different soil formations in the south-east. The soils were a sandy loam, a deep medium loam, and a heavy clay loam.

While the root-systems excavated maintained their individuality in certain horticultural characteristics and in their morphological identity, their general conformation and the ratio of roots to stem differed strikingly from

soil to soil. The influence of the rootstocks on blossom formation and growth characteristics of the scion was, in general, relatively the same on each soil.

There undoubtedly exists a varietal habit in a root-system, presumably a genetic factor. While the main scaffolding of some clonal rootstocks has a tendency to grow more horizontally—as in the case of Northern Spy—than others under similar conditions, it has now been shown that a number of interacting external factors influence the depth and spread of rooting in a marked degree.

In general, the soil proved all-important, and widely different rootstocks responded similarly upon each of the three soil types.

On the sand, the main root-system rarely went below 30 cm. which was probably the limit of readily available nutrients, but it spread two or three times as far as the branches. There were only a few roots growing vertically down to about 100 cm. in depth.

In the loam, the main root-system was again between 20 and 40 cm. in depth, but many vertical roots descended to the face of the ragstone rock anywhere from 120 to 300 cm., where they often appeared very active, in a stratum of relatively moist 'puggy' material. The dwarfed trees upon No. IX rootstock behaved similarly to those on the very vigorous No. XVI. Indeed, the former were in an exceptionally deep pocket of soil, and penetrated nearly 10 ft. in depth, so, once and for all, exploding the theory that dwarfingness and shallow-rootedness are synonymous. All the root-systems were generally less spreading than on the sand, being only about twice the branch-spread. The actual ratio of stem to roots was about double that on the sand—the roots in the poor sand having to spread farther for their requirements than in the good loam.

On the clay the same root-systems appeared much more compact, and the main scaffolding went deeper (to 50–60 cm.) than on the other soil types—probably as a result of the drying-out and cracking of the surface soil in summer. From that point, however, they grew out

almost horizontally and many roots were found growing upwards again. Few large roots over one year old were found at 100 cm. in depth, and it was obvious that the water-table in winter had deprived such deep roots of aeration and that they had in consequence succumbed.

Drainage, aeration, and the availability of moisture and nutrients are seen to be influencing the roots' behaviour in these different soils. Many subsequent excavations confirm and elaborate these conclusions.

Life-cycle of absorbing roots

The life-cycle of the absorbing roots, of which the scaffoldings so far described are but the sources and conducting channels, was next observed.

Direct observations of the living roots of apple-trees, on rootstocks Nos. IX, I, and XVI, were made through glass windows in carefully designed trenches. The data thus obtained, correlated with temperature and moisture conditions at different depths in the soil block, now add considerably to the knowledge of the factors governing the tree's activities below ground.

The date, number, length, and position of all new growth, apparent from the window, was mapped in weekly or monthly as the season required, over a three-year period. Under conditions of optimum temperature and moisture, usually in July, individual roots were found to make up to 3 mm. new growth in a day. In addition, photo-micrographic records were also made of the development of the rootcap, the elongation area, the root-hairs, the process of suberization, and the ultimate fate of the individual roots. The discovery of an exudate from the root-hairs deserves further investigation.

Though it was impossible definitely to classify the new roots, they could be divided according to size, those over 1 mm. thick being 'mains' and those under being 'laterals'.

Those which persisted were usually of the former class, becoming a permanent part of the root-system bearing different 'orders' of new laterals. The active absorbing

period of these young rootlets—before they began to suberize—varied from about one to four weeks according to season, temperature, and moisture conditions. They have been graphically described as growing into an area of the soil for a week or so, absorbing the nutrients and then passing out of the relatively exhausted area to other more favourable ones. In a single season, an area may thus be 'combed out' more than once. The correlation between these waves of growth and local temperature and moisture conditions is striking.

Soil temperature and moisture

When the soil temperature reaches about 45° F. root-growth becomes active before any leaves have burst. The top layers of soil warm up first in March and April, and so the activity begins there. Root-growth then increases rapidly to a 'peak' in June or July. There are usually 'smaller peaks' a month later and possibly with the autumn rains. While root-growth goes on both before and after active shoot-growth (May–Aug.) there is little activity from November to February, though some un-suberized roots usually persist in the warmer lower layers.

Under the conditions studied, soil moisture as well as temperature proved to be a limiting factor in root activity. The soil-moisture movements have been studied in fallow, in cultivated and grass orchard land by means of 'tensiometers' which record 'the direct and continuous measurement of the "suction force" of the soil'. A soil layer full of fruit-tree roots became much more rapidly depleted of moisture than the similar layer on adjacent fallow land. Grass accelerated the process, and even in a rainy summer the lower layers never became moist again.

Actually, most root activity was found in the area between 5 and 20 in., and there was twice as much in the first 2 ft. as in the second. Although the temperature conditions in the latter were apparently quite favourable, the summer rains only wetted a limited depth.

From these facts it is possible to construct a picture of

a section through the soil of a maturing orchard and to consider, in the light of the supply of moisture and nutrients, whether the trees are likely to be suffering from root competition and how the management factors are influencing the period of root and shoot activity.

V. SOIL IN RELATION TO FRUIT-GROWING

The planting of fruit in certain well-recognized areas had long grown into a safe tradition, and when the rapid development of the industry took place—during the past forty years—it was forgotten that the reputations of Kent, Hereford, Worcester, and Cambridgeshire had been built up on a conservative choice of land. It was mainly upon the deep loamy soils, such as the Ragstone and Brickearths of Kent, and the Old and New Red Sandstones of the west, that success had been attained with vigorous orchard trees of most sorts, though the Lias Clays of Evesham and the Calcarious Clays of Cambridgeshire, where well drained, had proved equally suitable for stone fruits. Two tendencies became evident as the fruit areas expanded. The well-tried 'safe' areas soon became largely occupied, yet fruit-growers still flocked where reputations had been established. In consequence, many new soil formations and types were planted to fruit without much consideration. Despite the publication of the *Survey of the Agriculture and Soils of Kent, Surrey and Sussex* in 1911, the possibilities of obtaining such a wealth of information to guide the intending planter were ignored until too late. Practically every area in Kent, for instance, was invaded by fruit plantations. Other growers definitely set their faces against 'over-crowding', and, later, against the orthodox type of orchard tree, electing to become pioneers in completely new areas and upon untried soils. This indiscriminate planting on all formations in the old fruit areas, and the exploration of comparatively new ones, such as the silts of Wisbech, the sandy soils of Norfolk, the 'gravels' and clay loams of Essex, and the weald clays of Sussex, naturally produced very diverse results in vigour, cropping, fruit quality, and disease susceptibility.

Although factors of time, material, and management varied in these orchards, it became obvious that an attempt to correlate tree performance with soil type would be invaluable.

Fruit-soil Surveys (1923–36)

In 1922 a beginning was made with such fruit-soil surveys in East Anglia and in the West Midlands. While the soil surveyor was to group and classify the soil types in the selected areas, the pomologist was to make an independent evaluation of tree growth and performance, taking into account, as far as possible, any contributing factors. These investigators were then to see if any correlations between 'good' and 'bad' tree performance and soil type existed.

Even in 1922 the nature and extent of the root-systems of long-lived fruit plants were to some extent appreciated, and it was realized that the character of the soil below the first 18 in.—the area usually most closely examined for annual crops—might be of the greatest importance in its effect upon tree performance. It was decided, therefore, to obtain a picture of the vertical section (profile) of the soil, with all the possibilities which this might reveal of root development and water movement, in addition to the texture of the surface layers.

The digging of thousands of holes was too lengthy and laborious, and so the soil auger, which has since become the indispensable companion of the horticultural advisory officer, came into its own. The soils were classified on the basis of the profile characters as investigated in the field. Separate samples for mechanical analyses were generally taken from the first 9 in. (surface soil), the second 9 in. (subsoil), and then usually in 12-in. depths down to 3 or 4 ft. or until the unweathered material was reached. The features revealed in these analyses of texture were used to confirm the profile characters as determined by auger tests.

In the later surveys the soil classification was based on the American method, i.e. 'all soils that are identical in

the origin of the geological "raw material", in the manner in which this raw material has been converted into soil, in their water circulation, in their general topographical position and in their soil profile are placed in the same "series" '. 'Types' and 'phases' were used as subdivisions of the 'series'. On the Lower Greensand in Kent as many as twenty-six soil series planted to fruit were established and sixteen series on the Hastings Beds. In addition, there were lighter and heavier 'types' or 'classes', and shallow and deep, well and poorly drained 'phases' of some series.

The practical applications

Six such surveys, covering a wide range of environmental conditions, have now been completed in some of the most important fruit-growing areas of England. The number of plantations and farms visited and examined is impressive and affords some measure of the number of soil borings (individually recorded on the map) and of the resulting analyses made. Where the soil series were not too intermingled, and where time and man-power permitted, soil maps, on a scale which will give the fruit-grower the detailed information which he requires, have been prepared. Not only does this assist the advisory officer in guiding the fruit-growers in the particular areas surveyed, but it has helped in elucidating certain general principles widely applicable to problems of soil selection and management in relation to kinds and varieties of fruits and their potential performance.

The surveys leave no doubt that soil conditions form one of the chief factors in successful fruit-growing, though they also demonstrate that certain kinds of fruit can be grown commercially on a much wider range than had been originally supposed. On the other hand, they conclusively proved that certain widespread troubles such as 'leaf scorch' and 'chlorosis' were intimately connected with definite soil characters.

The closely related features of moisture availability, of natural drainage, of soil depth and texture, have all been

shown—perhaps relatively in the order they are given—to be matters of considerable importance both in selecting a soil for fruit planting and also for selecting the kind, varieties, rootstocks, and methods of management to be employed.

The experience so far gained in the surveys has encouraged some generalizations. While it can no longer be said that light sands and heavy clays are unsuitable for fruit-tree growth—especially since that most difficult of dessert apples, Cox's Orange Pippin, is now to be seen flourishing on both—it is still necessary to examine these soils carefully for underlying material which would encourage conditions of drought, waterlogging, and poor aeration.

The medium loams, deep in profile and well drained, the fruit soils of the old dispensation, grow vigorous trees and fine culinary fruit, but they need special management if they are to produce high-quality dessert apples.

Plums generally make larger trees and produce better-quality fruit on the heavier soils. The particular requirements of apples, plums, and certain small fruits are now fairly well understood. There remains a whole field of exploration not only of the conditions most suitable for pears and cherries but of potential new areas where fruit can still be planted economically.

It has already been demonstrated by practical growers that much land which is of poor agricultural value—and which has indeed been abandoned to rough grazing—can, if properly selected, planted, and managed, carry valuable crops of high-quality fruit and give employment to a considerable staff. On the other hand, on much of our existing fruit land, which would be regarded as 'first-class' for arable and market-garden crops, it has been found necessary to adopt methods—such as tree ringing and grassing down—to counteract *the very virtues of the soil itself*.

VI. FRUIT-TREE NUTRITION

Field experiments on the manuring of fruit-trees both in the United States and in England had only produced

results of purely local interest which often conflicted one with another. Since nearly all the material used was of unknown potentialities, and the variability and influence of the soil sites was unmeasured, this is hardly to be wondered at. The methods of planning and the distances of planting then adopted were not suitable for such material and media, so that the separation of the various factors influencing the tree's behaviour was impossible. After thirty years' work, investigators had not been able to formulate any general principles, and the position was thus summed up in 1924: 'It cannot be said that the present-day systems of manuring in this country are in any way based on scientific data collected from past experiments on fruit trees since these previous experiments have not yielded results from which systems of manuring can be recommended.' It was further pointed out that large sums of money were being spent annually on manures in commercial fruit plantations without any sure evidence of their justification.

Pot-culture experiments.

Realization of this situation led to the initiation in the south-west of an extensive laboratory and pot-culture study of fruit plants, including the apple, currant, gooseberry, and strawberry, in February 1921. The plants were grown in pure sand and fed with nutrient solutions. Great care and forethought were taken in the planning and conduct of this experiment. The receptacles, the medium and tree material, the cultural and manipulative treatments, the moisture content, and the composition and application of the nutrient solutions were all carefully chosen, controlled, and adjusted so as to eliminate any varying factors.

Diagnostic symptoms of deficiencies

The series of eight treatments, ranging from a complete nutrient solution, through solutions from which nitrogen, potassium, phosphorus, calcium, and magnesium were omitted, to rain-water only, yielded the most striking contrasts in the performance of the young apple-trees

from the second year onwards. Significant effects were observed upon the time of bud-break and blossom-opening, upon the number of fruit-buds formed, the leaf and growth characteristics, bark colour, the fruit, and the development of the root-systems. 'Symptoms' by which the diagnosis of deficiencies could be made thus emerged. Most striking of all, perhaps, were the characteristic size, colour, blemish (scorch or blotch), pose (curl), and autumn tint of the leaves and the period and method of defoliation. The amount and type of growth and the success or failure of buds to 'break' were hardly less striking, and, as was only to be expected, the root-systems reflected the condition of the stem and branches, exhibiting differences not only in the total size of root but in the amount and type of fibre. Finally, the characteristic colour, 'finish', flesh texture, and taste of the fruit from individual treatments afforded another clue to deficiencies in the field and inspired yet another line of investigation into the market and keeping-quality of the fruit.

Similar success was obtained by using various small fruit-plants as biological indicators in pot experiments, though the analogy with the apple must not be carried too far, since these fruits showed particular preferences.

Whilst it has been stressed that some of these 'symptoms' may be indicative of more than one type of deficiency, and may indeed be induced by other factors affecting the metabolic processes of the plants, entirely new methods of approaching manurial problems of the fruit plant in the field were thus opened up. The advisory officer has been furnished with methods of diagnosis which in his critical hands can be used to the immense benefit of the fruit-grower.

Chemical analyses

An exhaustive series of chemical analyses of the 'major' mineral contents of the various portions of these experimental trees, and of others in field trials, has been made. The deficiencies observed in the trees have been reflected in the relatively small quantities of the respective elements,

as compared with normal trees, found to be present, and in the effects upon the contents of other elements.

The leaf-scorch problem

From a practical point of view, the knowledge acquired with regard to the balance and deficiencies of potash and nitrogen has perhaps been the most outstanding. The manifestations of 'leaf scorch', which were unwittingly increased by the repeated dressings of nitrogenous manures so commonly applied to counteract them, were widespread in English fruit plantations. They defied all attempts at solution until the diagnostic symptoms of potash-deficiency, and the importance of the nitrogen–potash ratio, were demonstrated. The deductions which were drawn from these findings have profoundly influenced manurial and cultural practice. Not only has the value of potash dressings become recognized, but the use of nitrogenous fertilizers has been more intelligently associated with the observed requirements of the orchard. Again, fruit-growers in this country had been accustomed to give heavy and repeated dressings of phosphates and lime. When it became clear that the symptoms of phosphate deficiency which appeared so clearly in the pot-culture experiments were not found in the orchard, and that the omission of calcium did not have the popularly expected results, commercial practice was modified in consequence. Soil and climate are, however, vitally important factors in determining the requirements of the tree in the orchard. The marked response of apple-trees to phosphatic dressings on the Moutere Hills in New Zealand, and to nitrogen in parts of America, are but two examples.

Manurial experiments in the field

As a result of this work the study of fruit-tree nutrition under different soil and climatic conditions was once again attempted.

Field experiments based on these findings have been developed in many parts of the country both to prove their

applicability under contrasting environmental conditions and to remedy special deficiencies where these have become obvious. The results of such experiments have been most encouraging and seem likely to continue to yield increasingly valuable information, especially when the results in the orchard can be translated into chemical terms in the laboratory.

Though fruit-trees which have long exhibited deficiency symptoms have often been shown to manifest a slow response to remedial treatment—in the case of potassium-deficiency in apple-trees dressings of 3–4 cwt. of sulphate of potash may not show results for several years—the observable effects of manurial applications have now become the rule rather than the exception. It is even possible to detect significant differences in response to manuring of trees of a single variety grown side by side but upon different rootstocks—some of which are now proved to be 'poor potash feeders'.

The results of many of these field trials, combined with the observations made during fruit-soil surveys, have made it possible to some extent to group together different kinds and varieties of fruit according to their nutritional requirements. Plums and black currants generally are known to respond to high nitrogen conditions; apples, gooseberries, and red currants require relatively high potassium. Yet knowledge of varietal preferences has shown that qualifications of these generalizations are necessary. The idea of finding a uniform method of manuring individual crops has been replaced by an appeal to the grower's judgement. He is asked, in drawing up his manurial programme, to consider the modifying influence of class of fruit, of variety, of rootstock, of cultural conditions, of general environment, and of the current season.

Indiscriminate interplanting of different kinds and varieties of fruit renders intelligent manuring impossible. The grass orchard and the cultivated plantation largely lose their identity in the scheme which relies upon 'high' and 'low' cultivations as factors for controlling the trees' internal and external balance.

There are indications that the rapid replacement of organic manures by purely chemical fertilizers, as a result of the scarcity prices of the former and of the progress of mechanization on the specialized fruit farm, may bring its own problems. The mechanical and moisture conditions of orchard soils, where normal crop rotation is impossible, yet where clean cultivation has been long maintained, need careful investigation. Preliminary studies suggest that this may be well repaid.

VII. DIRECT INJECTION OF FRUIT-TREES FOR THE DETECTION OF DEFICIENCIES

Within the last few years another method of diagnosing nutritional deficiencies has been brought within the range of practical application, namely that of direct injection of liquids into the tree.

This development grew out of an investigation, from a biochemical standpoint, of the phenomena of rootstock–scion relationships. An attempt has been made to obtain by spectroscopic analysis as complete a picture as possible of all the inorganic salts in the ash of different combinations of rootstock and scion. Some twenty-odd elements, in addition to those chemicals used in artificial manures, have been found to be present, many of them in minute quantities. Iron, for instance, which is known to be essential for the healthy growth of fruit-trees, formed only about one five-hundredth part of the total of which potassium might occupy as much as one-quarter or even a half. Again, molybdenum was found in the roots and rootstock stem of very dwarf apple-trees on No. IX rootstock, but it was not found at all in the vigorous trees on rootstock No. XII. This suggested that rootstocks might select different substances, perhaps in different proportions, or even use them differently. Again, certain elements (such as aluminium) were not found to be distributed uniformly over the whole tree, and it appeared that, as the sap travelled up, some elements might be withdrawn more rapidly than others. The importance of the functions of these so-called 'minor' elements called for inquiry. Were

they in any way responsible for differences in rootstock influence or in varietal response? Did any of these 'trace' elements, like lithium, exert any influence upon the known resistance of certain varieties to disease?

While an improved technique for obtaining rapid quantitative analyses of these elements was being developed, methods were also being devised by which the part played by some of these elements in the tree could be elucidated. Since the majority of soils contain most of these elements already, and since it would be impossible to detect whether they remained available to the plant or became 'locked up', or whether they might even bring other substances into solution and so indirectly influence the behaviour of the tree, it was decided to try introducing the desired chemicals direct into the tree. Although tree-injection methods are of ancient origin they had largely been used for purposes either of studying the mechanism of water movement or in attempts to control diseases and pests on the tree as a whole. The chief object now was to make exact comparisons of the effect of different liquids locally injected. The main experiments were based on the 'leaf pull' of the growing tree, and upon the natural negative or suction pressure at the point of injection, rather than upon methods of injection under pressure.

The first essential was to obtain a precise knowledge of the distribution of the substances so injected, of the directions in which they travelled, and of the portions of the tree which they ultimately affected. This knowledge was obtained by the use of suitable dyes, of lithium, and of certain substances selected because their course could be traced by slight damage to the foliage. Later, the major elements of artificial manures, from which known responses might be looked for, were used for the same purpose. The vascular anatomy of the fruit-tree was thus revealed in great detail, and the effect of the arrangement of the leaves on the stem upon the course of the liquids introduced closely studied, with the object of localizing the injections.

The framework of the tree—stem, crutch, branches,

spurs with their resulting conducting 'strands'—the possibilities of cross-transference of substances in solution, the direct connexion between certain portions of the root-system with individual branches, and the moisture of the air and the soil, all had to be studied in the light of their influence upon the course of the injection. Incidentally, this study has afforded the horticulturist a clear picture of the interrelationships between individual roots, branches, and laterals in his fruit-trees. Questions of maturity of foliage, of size of tree as determined by cross-section of stem, and of vigour as determined by growth-rate had to be taken into consideration in indicating the safe seasons, the durations of injection, the concentrations of the fluid, and the dosage. The different types of damage which sometimes resulted, its causes and avoidance, were investigated.

Gradually a technique has been evolved by which inter-veinal portions, leaf tips, leaf stalks, shoot tips, branch tips, individual branches, branches with corresponding roots, and whole trees can be used with a great measure of precision as injection-points. For the purpose of diagnosing mineral deficiencies, the inter-veinal and individual branch injections hold out great possibilities. It is far easier and quicker to detect the differences in colour and rapidity of growth by comparing the treated and untreated leaf 'plots' separated by only secondary veins or individual neighbouring branches on the same tree, than it is to apply a series of chemicals to the soil and wait in the hope of obtaining statistical data to demonstrate the effects of the application. It is also certain that the observed effects are the direct result of the substance injected. Moreover, comparatively rapid diagnosis of deficiencies can be made, the time varying from three to ten days. By applying these methods, iron, nitrogen, phosphorus, and boron deficiencies have already been detected, and the iron-metabolism has been found faulty in orchards over wide areas in Kent.

For curative purposes, either branch or whole-tree injections would be most suitable. Some promising cases of the rapid improvement in the growth and foliage of

whole trees have been recorded. In cases of chlorosis, trees have been rapidly restored to vigorous growth, and the effect on the whole tree has been seen to persist for a second season, but it is not claimed that such 'whole-tree' injections—although in cost they have been reduced to a few pence—would be recommended, except in extreme cases, as a commercial practice. However, while the normal applications to the soil of the element indicated are taking their inevitably slow course, such methods might well save the situation in cases of serious depletion.

Branch injection has already been used in a preliminary investigation of its possible value in the case of diseases such as Silverleaf in plums. It has also been used successfully to vary the composition of fruit on individual branches for purposes of studying the effect on respiration and keeping-quality.

VIII. FRUIT AND ITS MARKET QUALITY

Even when the fruit-grower has taken into consideration all the factors for the balanced growth and cropping which are inherent in his plants or influenced by their environment, he is faced with the handling of a highly perishable product. To find a ready market it must possess certain qualities of firmness and appearance, largely governed by the right selection of variety, skilful management, and care in handling.

The dull, 'striggy', squashy, bruised, and blemished fruit stands no chance to-day with critical buyers who know that well-grown samples of the varieties best suited for their purpose are obtainable. While progress in methods of sorting, grading, packing, and general presentation, under the aegis of the Ministry of Agriculture's Marketing Branch, has kept pace with the increasing supplies of home-grown fruit worthy of a standard National Mark, investigators have made the canner and the jam-manufacturer acutely conscious of the importance of their 'raw material'. Not only has the Campden Research Station been instrumental in developing a large canning industry in this country which affords a new outlet for

English fruit, but it has indicated the varieties and their condition most suitable for this purpose. Meanwhile outlets for lower grades of fruit, of which some proportion is inevitable, are being explored, in order that they may be kept off the fresh-fruit market and yet saved from waste.

The considerable supplies of home-grown apples now necessitates an orderly marketing spread over an extended season. This presupposes a product capable of being stored and storage methods which can prolong the season with certainty. Research has come to the assistance of the industry in both problems.

Orchard factors and storage qualities

A comprehensive survey of orchard conditions which might affect the storage qualities of apples was initiated in the south-west in 1927. The material used was of known history, supplied from the pot-culture experiments, from research-station field-trials, from county demonstration plots, and from commercial orchards under observation during soil-survey work.

The fruit was chosen as 'typical' of the treatment under examination, it was picked and transported with extreme care to avoid bruising, and, after final selection, was placed in single-layer trays both in ordinary uncontrolled store and in a low-temperature store, controlled at 1° C., with a humidity of approximately 90 per cent. At the same time the chemical composition of sample fruits was ascertained in an attempt to correlate this with storage qualities.

A large number of factors, many of which proved to be closely interrelated, were investigated. First, there were the inherent qualities such as varietal and rootstock differences and age of tree. Varieties differed widely in their length of storage life and in the ultimate form of breakdown. Under some conditions fruit from trees of the same variety grown adjacently but upon different rootstocks behaved very differently in store, while the fruit from young trees generally possessed poor keeping-quality. The effects of on- and off-year, of heavy and light crops, and of fruit size showed that heavy crops and the smaller

grades of fruit produced better storage characteristics. Similarly, the effects of hard and light pruning, bark-ringing, and fruit-thinning could be traced in the store. Most important of all were the effects brought about by deficiencies or excesses of nitrogen and potassium and by 'high' or 'low' cultural conditions related thereto. While a condition of high nitrogen can usually be associated with early breakdown and the development of rots in store, apples when grown in grass can stand considerable dressings of nitrogen without any ill effects upon keeping-quality. Grass, which rapidly produces a condition of low nitrogen, was found both to enhance the colour and appearance of dessert apples and also to prolong their storage life. A return to clean cultivation had a drastic effect in the other direction. The susceptibility of high nitrogen fruit to bruising, and its loss of colour, are also obvious. Though it was interesting to find that, under the conditions of ordinary storage, potassium-deficient fruits showed little breakdown, they collapsed prematurely in 'cold' store. Experience has shown that high potassium fruits generally exhibit resistance to rots and keep well at the optimum temperature required for each variety. Finally, time of picking was shown to be very important. Though the close interrelationship of many of these factors makes it impossible to predict how any one of them will affect a crop without considering the environmental conditions as a whole, yet 'certain of the factors exert very powerful effects and usually produce dominant influences'. Chief amongst these are marked deficiencies of nitrogen and potassium, high and low cultivations, and bark-ringing. If these facts are considered in relation to the nutritional and cultural findings already described, it will be seen that the grower now has a very large measure of control over the production of fruit of the desired quality.

While the data relating to chemical composition revealed many interesting comparisons—such as the consistent difference in chemical constitution of different size-grades of apple—these investigations did not suggest that any simple relationship with storage qualities exists. For

instance, the low-nitrogen fruit grown on grass kept well, but that produced by ringing was particularly subject to breakdown. Investigations into this aspect of the problems have been developed under the auspices of the Food Investigation Board and some suggestive facts about the varying susceptibility of apples to fungal rots have been obtained.

The fruit, its behaviour and storage

The investigations of the Low Temperature Research Station, Cambridge, and of the Ditton Laboratory, East Malling, have now taught the fruit-grower to look upon the end product of his labours, his fruit, as living material. The highly complex life-cycle of the apple, from the bud stage to its final decay as a senescent fruit, has been traced through the periods of initial cell multiplication and of increase in cell size accompanied by storage processes to the vital change when it can no longer 'build up' and 'repair' its tissues. It is usually about this period, called the climacteric, that the fruit is gathered. After this, the chemical changes which bring about the maturing of the colour, the ripening of the flesh, and the fullness of the flavour begin. Since, after picking, this living fruit continues to absorb oxygen from the air and give off carbon dioxide, it is highly necessary to postpone this climacteric if the fruit is to be stored for any length of time. While low temperatures slow down this period for a time, they do not suppress it sufficiently. A consideration of all the facts led to the idea of controlling in addition the atmosphere in which the fruit was stored. Though the absence of oxygen indefinitely postponed the climacteric, other factors injured the fruit-tissues. The presence of carbon dioxide—which the fruit itself gives off—was found to decrease the fruit's respiration. Hence a controlled balance of oxygen and carbon dioxide in the atmosphere and maintained constant in gas-tight refrigerated chambers came to be applied on a commercial scale.

With increase of knowledge and experience the processes of gas storage became more precise and are now

being extended to pears and even to plums. The vital importance of picking before the climacteric, of wasting no time between orchard and store, of considering the particular requirements of individual varieties, and of guarding against their unconsidered mixing in the store have all been elucidated and demonstrated. It has been shown that certain volatile substances such as ethylene accumulate during ripening and actually accentuate the process. The value of these discoveries to the industry at a time when the quantity of high-quality apples was rapidly increasing upon the market cannot be over-emphasized.

Once it was appreciated that the fruit would keep at least twice as long in such atmospheres as in air, that it came out firm and immature in colour, and that it kept well for considerable periods after removal from store, commercial storage capacity rose with amazing rapidity from 1933 onwards.

IX. THE FRUIT PLANT AND DISEASE

To ensure regular crops of good-quality fruit, healthy plants are a *sine qua non*. The fruit-grower has always been most interested in the direct control of diseases and pests. Without doubt the pioneer contributions of the early plant pathologists in working out 'life-histories' and in demonstrating their practical importance to the fruit-grower quickened his faith in horticultural research generally.

Two volumes, designed for the practical man, have recently appeared summarizing the advances made by the entomologist, mycologist, bacteriologist, and virologist towards a more complete knowledge of an ever-lengthening list of pests and diseases and a choice of methods for their control. Another volume has dealt with the development of spray chemistry, and yet another reviews the improved methods and machinery available for the application of insecticides and fungicides. In the light of all this information, the modern spray calendar presupposes, for the production of a sound apple crop, a

minimum of from 5 to 7 routine winter, 'delayed-dormant', spring and summer applications, to which may be added a number of subsidiary sprayings to counteract special epidemics. Hardly less thorough schedules are recommended for other fruit, even the strawberry and the blackberry being no longer excluded. The ready control of the 'big bud' mite of black currants, of the raspberry beetle, and of apple sawfly are a testimony to the value of an exact knowledge of the pest and an exhaustive evaluation of the best chemical controls. No attempt can be made here to summarize this impressive mass of detail, but the horticulturist sees running through it certain general tendencies which are opening up promising fields for investigation.

First and foremost the plant pathologist has learnt to take the plant as well as the disease into consideration. While he has long realized the possibilities of resistant varieties, and has not infrequently turned plant-breeder, with variable success, he has now gone farther and taken the pomologist into collaboration, realizing that environmental conditions may affect the relationships between the plant and the causal organism. It is suggestive to reflect that many of the major troubles of yesterday are the minor and exceptional worries of to-day. Twenty years ago it was considered a rash speculation to plant Cox's Orange Pippin and Worcester Pearmain because of the prevalence of Apple Canker, Powdery Mildew, and Apple Scab. An intelligent revision of methods of management, manuring, and spraying technique, combined with a careful adjustment of the spray schedule to minimize spray-injury effects, has now made these two varieties the chief commercial dessert apples of England. Amongst small fruits the widespread control of American Gooseberry Mildew affords a parallel case. More and more attention is being given to the established fact that the 'condition' of the fruit plant in any particular environment may not only affect the ease with which it can be sprayed, but also its resistance to the disease organism and its reaction to control measures.

Similar considerations undoubtedly affect insect attack. Individual pests become associated with particular environments. Isolated observations suggest an even closer relationship. From sixteen randomized Cox's Orange Pippin trees variously injected in 1934 with water and chemical solutions, entomologists were able to select six which were much less heavily infested than the rest with Leaf Hopper and Red Spider. It was found that these were the trees that had been injected with a solution containing 0·25 per cent. potassium phosphate plus 0·25 per cent. urea. Again, the Strawberry Aphis—a carrier of virus disease—has never been found to remain and reproduce on the wild strawberry (*Fragaria vesca*) in its natural surroundings. Under cultivated conditions, *F. vesca* proves a ready host. The healthy 'strain', the optimum environment, orchard practice, and hygiene now receive at least as much attention as mechanical trapping, attractants, and chemical specifics.

Secondly, one great revolution in the control of insect pests has been the introduction of egg-killing washes, towards the standardization and improvement of which scientific investigation has played such a valuable part. Aphis and Apple Sucker, the inveterate enemies of the fruit-grower, are now banished by the tar oils before the growing-season starts. The Capsid and the Red Spider have similarly been 'put in their places' by the petroleum oils. More attention can now be given to those less obvious pests and diseases the dire effects of which develop in the store.

Again, mycologists and entomologists have come together with the chemists to devise safe and effective programmes of combined washes, which save time and are within the grower's ability to apply. This work has included the detailed and precise exploration of the insecticidal and fungicidal properties of a wide range of chemicals hitherto not employed for such purposes. It has also led to fundamental studies of the toxic and phytocidal principles of these substances. The behaviour of these washes on the plant has been studied and the use

of 'wetters', 'spreaders', 'stickers', and 'lubricants' has all been evaluated.

Improvements in machinery and apparatus and a better appreciation of the value of 'power', 'mobility', and 'direction' came at this very opportune moment, to make possible a compromise between the old 'mist' and 'drench' methods, and to enable the grower to get round effectively during the brief yet critical periods. This rapid control of the diseases and pests of fruit has been brought about not only by the teams of workers at research institutions and the multiplication by advisory officers of field trials under widely differing environmental conditions throughout the country, but by the enlightened collaboration of a number of industrial concerns interested in the possibility of an extended application of their products.

Thus, while a wide exploration of new specifics is being carried out on an analytical and statistical basis, and detailed studies of the causal organisms of disease are being intensified, varietal susceptibility and resistance, multiplication and maintenance of disease-free plants, possibilities of isolation and hygiene, use of immune rootstocks and of resistant 'frameworks', adaptations of pruning and training and of cultural and manurial practices are all being studied in relation to the health of the fruit plant.

The horticultural investigator, with the indispensable aid of investigators in the more 'formal' sciences, has, as a result of exact experimentation, accumulated a considerable body of precise information relating to 'the character and quality of the materials planted, the various orchard practices and the treatment of the produce of the orchard' during the past twenty-five years. In claiming this steady advance in the standardization of fruit production it is necessary to emphasize the part played by this comparatively young and vital industry itself. The modern fruit-grower has developed his ideas and methods in close collaboration with the research institutes which he has been so ready to support, and with which he has always been most ready to exchange ideas. The horticulturist has

certainly shown 'the scientific man's faith in experiments' and has gained an ever-increasing control over his material, so perhaps it can at length be pleaded that fruit-growing at least 'can step out from being an art to becoming a science'.

SOME PROBLEMS OF ANIMAL NUTRITION

By CHARLES CROWTHER

GENERAL REVIEW

THE twentieth century, with little more than one-third of its course run, has seen a remarkable advance in our knowledge of nutrition. At its opening the current teaching was content to regard the values of foods or rations as being adequately defined by their content of available energy (or gross digestible energy) and of digestible protein. On this basis two rations that were equal in energy-supply and protein-supply were to be regarded as of equal value, and the actual constituent foodstuffs from which they were compounded might consequently be regarded as of little or no significance except in so far as they might influence factors such as palatability, or the quality of products such as milk, body fat, or butter fat manufactured by the animal from its food. Mineral requirements were regarded as being so small that deficiency was hardly likely to arise in farm practice, except perhaps as regards the supply of calcium and phosphorus where rapid bone-formation or high milk-yields were in question. Practical experience that did not harmonize with these views was largely disregarded, not as being unimportant, but as either inexplicable or based upon faulty deductions.

The dawn of the new century, therefore, found the attention of nutrition investigators largely directed to the study of energy relationships and the nature of the proteins, and in both fields notable advances were already well under way.

In the matter of energy-supply the first advance in the solution of many discrepancies between theory and practice had just been made, through the successful establishment of the conception that the production-values of foods are determined by the 'net energy' placed at the disposal of the animal rather than by the total metabolizable energy.

For the development of this conception in its application to the feeding of farm animals we are indebted, above all, to the work of Kellner, in Germany, and Armsby, in America, on which are based, so far as energy-values are concerned, the modern methods of scientific control of rationing now so widely used in practice.

In the domain of protein research, also, the way to a more precise understanding of their functions in nutrition had been opened up at the end of the last century by the brilliant work of Emil Fischer and others, which had demonstrated that these hitherto mysterious and baffling nitrogenous substances were definite chemical entities of very complex natures, built up from a variety of 'structural units' belonging mostly to the class of amino-acids. Subsequent research has demonstrated that individual proteins differ widely with respect to the kinds and proportions of these 'structural units' present in them; and furthermore, that in the animal the proteins of the food are assimilated in the form of these 'units' into which they are resolved by the proteolytic enzymes of the digestive juices.

Equally important was the discovery that some of these amino-acids are absolutely essential to the animal for specific purposes and must always be present, therefore, in the products of digestion of the food proteins in the animal if successful results are to be achieved. In other words, in considering food-supplies the *quality* of their protein, as determined by their 'make-up' of these amides, amino-acids, &c., must needs be taken into account as well as the *quantity* of proteins present.

Within the first decade of the present century came the momentous discovery of the vitamins, and in the second decade the revival of interest in the functions and practical significance of the mineral ingredients in the dietary.

More recently still has come the increase of knowledge of the functions of the internal secretory glands (pituitary, thyroid, &c.), and of the agents (hormones) by which their control over vital processes is exercised.

Out of these developments has arisen the study of

deficiency diseases and less acute phenomena of malnutrition bearing closely upon the health and constitutional vigour of animals, which now so largely dominates the field of nutrition research.

Cutting across all these lines of study of individual factors is the newer work on the correlations between different factors and their interdependence on each other. A common example of this is found in the interaction of the supplies of calcium and phosphorus, or, more broadly, of the basic and acidic ingredients in the diet. 'Balance' in the proportions of individual factors present is now being revealed as a consideration that must be taken into account alongside the actual amounts of each factor supplied in drawing up the ideal dietary.

The intensive concentration in recent years upon the newer developments, often loosely described as the 'new science' of nutrition, has tended to produce, especially in the lay mind, a distorted conception of nutrition as being primarily a matter of supply of vitamins and of minerals. This has led to the indiscriminate addition of vitamin and mineral preparations to all kinds of diets, regardless of whether such additions will remedy an existing deficiency or imperfection of 'balance' in the diets—the only conditions under which benefit from the additions can be expected. This practice is the more to be deprecated in that there is always the risk that excess supplies of certain factors, such as may be occasioned by such additions, may be actually detrimental in their effects.

The newer knowledge of nutrition has in no sense replaced the old science, but has merely amplified it and made its application to practice more precise and efficient. To say that 'feeding by calories' is out of date would be just as absurd as to say that improvements in the motor-car engine have eliminated the necessity for a supply of fuel in the tank.

Just as the motor engine works smoothly only when all the essentials are present and working together harmoniously in a co-ordinated effort, so, also, successful nutrition cannot be explained in terms of any one factor but

must be attributed to the co-ordinated action of the whole complex of factors embodied in the ration, supplemented by other non-nutritional factors which are provided by good management. If a ration be imperfect the effects of adding different materials to it will be determined by the extent to which they remedy its deficiencies or improve its 'balance'. Unless they are required for some such purpose the additions will at best be ineffective and often may do positive harm.

From this brief outline it is clear that the advance of nutrition science during the present century has been made on a very broad front. So far as this advance has markedly affected the practical feeding problems of the farm this has perhaps been most clearly evident in the following directions:

1. The more precise definition of the possibilities and limitations of the energy concept, with consequent improvement in methods of ration control.
2. Increased knowledge of the nature and mode of utilization of proteins.
3. Increased knowledge of mineral metabolism.
4. Development of the concept of 'balance' in the interrelationships of various factors.
5. The discovery of the importance of 'accessory factors' (vitamins, hormones, &c.).
6. Relationships between nutrition and disease.

To some of these a more extended reference is made in the following pages.

PROTEIN PROBLEMS

Biological values of proteins

The fact that proteins differ in nutritive value is no new discovery. Nearly 100 years ago Majendie demonstrated the inferiority of gelatine to meat protein, and in the seventies Escher found in experiments with dogs that this inferiority could be made good by feeding the amino-acid tyrosine along with the gelatine. The final proof could not be brought, however, until at the end of the century the

brilliant work pioneered by Emil Fischer demonstrated the true chemical character of proteins as complex condensation products of relatively simple nitrogenous compounds, belonging mainly to the class of amino-acids.

It was further demonstrated that these amino-acids, &c., represent the final products into which the proteins are broken down in the processes of digestion, so that the supply of protein to an animal is tantamount to the provision of a mixture of amino-acids out of which it reconstructs the proteins of the animal body and animal produce.

These discoveries stimulated a great interest in the study of the make-up of different proteins which must long continue before the whole field is covered.

The next definite advance was made by Osborne and Mendel in 1914 with the demonstration that the amino-acid tryptophane is essential for the maintenance of the animal, and lysine for growth. Subsequent research demonstrated that whereas some of the amino-acids can apparently be synthesized within the body from other materials, there are others which cannot be so produced and must therefore be present as such in the proteins of the food. Out of the twenty or more amino-acids whose presence in one or other of the proteins has been demonstrated more than one-half fall into this latter class, which along with the two mentioned above includes histidine, leucine, phenylalanine, valine, arginine, and methionine. All these are essential for normal growth, and some at least are probably essential for the support of other body functions, such as lactation, egg-production, and wool-production.

In making up the food-supply of the animal, therefore, special care must be taken to ensure that the proteins included supply all the *essential* amino-acids.

Furthermore, we ought as far as possible to select a protein or mixture of proteins that will give just sufficient of each essential amino-acid, and cover the general protein needs without waste. Such, at any rate, are the requirements for physiological economy, but in practice overriding considerations of financial economy may at times

compel the adoption of rations that involve considerable physiological waste. Such rations must, however, still comply with the need for supplying the essential amino-acids.

The ideal ration from the point of view of protein-supply would be one that supplies all the amino-acids needed in proportions similar to those in which they exist in the animal protein that is to be formed (growth-tissue, milk, &c.). Such a ration would meet the protein needs of the body with a minimum intake of protein. Unfortunately, the determination of the amino-acid make-up of the proteins is still a difficult and tedious business, and it will be long before we have at our command knowledge sufficient to make practicable this ideal blending of our proteins to secure a perfect amino-acid balance. In the meantime, we can do little more than adopt the expedient of seeking safety by including in the ration a variety of proteins of different origin, trusting that *between them* the proteins of the various foods we blend together will at least provide the necessary minimum of each of the *essential* amino-acids.

Since the various proteins differ in their amino-acid constitution, it is clear that differences must exist in their nutritive values when used as the *sole source* of protein to the animal, and their relative 'biological values' under such conditions can be tabulated. In rations of mixed proteins, however, such as are invariably used in farm practice, the biological value of a particular protein may vary according to the nature of the remaining proteins of the ration. The protein of beans, for example, is richer in lysine than that of linseed and therefore it will have a higher biological value than the latter if added to a ration whose mixed proteins are deficient in lysine, whereas its biological value may be no higher, or even lower, than that of the linseed if added to a ration that is already adequately supplied with lysine.

For practical purposes, therefore, it is the *supplementary* value of each individual protein that counts, the biological value of the ration protein, as a whole, being determined

by the character of the whole complex of proteins present in it. Animal protein *per se* is naturally more likely to be complete and well balanced in its amino-acid constitution than plant protein, but it does not necessarily follow that it will always make a more effective supplement to the proteins of rations to which either may be added. Much of the prevalent misconception as to the comparative merits in feeding-practice of animal and vegetable proteins would disappear if this point were more generally understood.

The mixed rations used in farm practice are probably never entirely lacking in any essential amino-acid, but they may vary considerably with regard to the total amount of protein required to provide the necessary minimum of the essentials. The accumulation of information on this point is a necessary preliminary to further advance in the control of protein rationing.

There is a tendency to regard the whole value of protein as being determined by considerations of amino-acid supply as outlined above, but this will probably prove to be too narrow, and there is already evidence of the exercise by various proteins of specific nutritive effects that are not readily explicable in terms of amino-acid constitution.

Bacterial synthesis of protein

Although it is commonly taught that protein in the body can only come from protein in the food, there is a considerable volume of experimental evidence that to a certain extent the needs of nitrogen metabolism in the animal can be met by the supply of individual amino-acids, or even of the simplest types of nitrogenous compounds, such as urea and ammonia. The explanation of these phenomena that has met with the widest acceptance is based upon the bacterial activity to which the food is subject at certain stages of its passage through the digestive tract, and upon the knowledge that bacteria can synthesize protein from these simple nitrogenous compounds ('amides') which are usually present in small proportions in food-supplies. This explanation receives further support

from the fact that it is particularly, if not exclusively, in the ruminant class of animal, where bacterial activity is most pronounced, that this evidence of apparent protein synthesis has been obtained. The procedure envisaged in this explanation is that the bacteria in the rumen assimilate the simple nitrogenous compounds from the food, build them up into protein in the bacterial tissue, and then, when the bacteria die in the more remote parts of the intestines, this protein becomes subject to the action of the proteolytic enzymes and represents an addition to the supply of protein available to the animal. That some bacterial synthesis of protein along these lines does take place with production of sufficient protein to be of quantitative significance, can hardly be questioned. Few of the experiments, however, have been sufficiently free from defects of planning to make their results conclusive. Even where evidence has been obtained of effective replacement of some part of the protein-supply by non-protein compounds it is not clear whether the latter have done more than take over certain functions not specific to protein-supply that in the control ration were being discharged by protein, that is they may have been *sparing* protein without themselves actually assuming the form of protein, just as an addition of carbohydrate to a ration will often effect an economy in the use of protein.

The problem is still *sub judice*, but whatever the ultimate solution there can be no doubt as to the possibility in farm practice of working to much lower levels of true-protein supply if this is accompanied by a supply of the simpler nitrogenous compounds referred to. This possibility is receiving close attention in countries, such as Germany, where self-sufficiency in supply of nitrogenous nutrients is a national aim.

Protein minimum and optimum

In stating protein requirements it is necessary to be clear as to the precise significance of the figure given. Experimental work on protein requirements usually takes the form of determining the lowest amount of food protein

that will maintain the animal body in protein equilibrium, i.e. neither gaining nor losing protein. The figure obtained is thus the *minimum* requirement under the conditions of the experiment. Experiments are necessarily confined to limited periods and strictly speaking the conclusions drawn are only valid for such periods, until confirmed either by experimental work or practical experience over longer periods. This consideration must be kept in mind when applying the results of experiments to farm feeding-practice, especially where the experimental results suggest that a very low level of protein-supply will be adequate.

In short-period studies of maintenance requirements, for example, protein equilibrium has been maintained at levels of protein-supply much below those found to be desirable in practice. Over short periods the maintenance protein requirement of cattle may be covered by a daily supply of 0·3 lb. digestible protein per 1,000 lb. live weight, but when this has been tried over long periods both in America and in Denmark it has been found that the health of the cattle eventually suffered in comparison with that of others which were getting a rather more liberal supply. In the Danish test this was very obvious in the appearance of the animal, which was quickly improved when the supply of protein was increased.

Practical experience also indicates the undesirability of basing the protein standards for *production* purposes on the experimental minima. For example, a working horse expending a certain amount of energy needs no more protein to keep it in protein equilibrium than a fattening bullock of the same weight storing up the same amount of energy, but the application of the bullock-feeding standard to the feeding of the horse would certainly not give satisfactory results in practice.

It is thus necessary to discriminate between the 'absolute minimum' protein requirement, which is of scientific interest only, and the 'optimal minimum' or 'practical minimum', this being the lowest amount that in practice will cover the protein needs of the animal consistent with the maintenance of health and vigour and the efficient

discharge of any productive effort required. The protein data in tables of feeding-standards must clearly be based upon the latter, and must therefore be interpreted as representing the minimum amounts of digestible protein of average 'biological value' that will be required by the average animal under average practical conditions to perform efficiently the task assigned to it.

Protein and Meat-production

From the scientific point of view, meat-production is the resultant of a complex series of chemical processes within the animal body which end in the production of two quite distinct materials—protein and fat. The former predominates in the 'lean' part of the meat and the latter in the 'fat'. Using the term in its popular sense, 'meat' thus consists of a more or less intimate mixture of water, proteins, and fat.

The protein of meat, which corresponds roughly to the 'lean', can only be produced out of the protein ingredients of the food, whereas the fat can be produced out of either protein, oil, or carbohydrates supplied in the food. Hence, any digestible ration if given liberally will produce fat, but whether it will at the same time produce any 'lean' will depend upon the amount of digestible protein (surplus to the maintenance requirement) in the ration. In so far, therefore, as the proportion of 'lean' to fat is determined by the food-supply it is essentially a question of the balance of proteins to non-protein ingredients in the ration.

Either a deficiency of protein or an excess of non-proteins will result in a low ratio of lean to fat. Whether a liberal supply of protein will produce more 'lean' in the carcass depends partly upon the proportion of non-nitrogenous nutrients by which it is accompanied in the ration, and partly upon the inherent capacity of the animal to convert food protein into meat protein.

Within the limits imposed by the latter condition, and provided that the supply of oil and carbohydrates in the ration is adequate to cover the general maintenance needs

of the animal, increase of protein in the ration should produce more lean tissue in the body.

The dominant factor, however, which determines the extent to which lean tissue can be produced in the animal is its inherited capacity for growth. That individual animals show great differences in this capacity is common knowledge, and underlies the breeder's work of mating and selection for meat-production qualities. Each animal is born with its specific capacity to make growth (lean tissue, bone, blood), and it is the business of feeding and management to secure that this capacity is fully utilized up to the point at which the animal is ready for sale, whilst at the same time securing that the *growth* is accompanied by just sufficient fat-production to give the particular balance of lean to fat in the carcass that is desired.

For purposes of discussion, it is convenient to treat growth and fattening as if they were entirely separate processes, but in the practical feeding of the growing animal the growth proper is always accompanied by a certain amount of fat-production. In the earlier stages, while the growth impulse is still strong, the live-weight increase of the animal is primarily a growth increase and only to a relatively small extent due to deposition of fat. As the animal ages and the intensity of the growth impulse decreases the increase of live weight becomes more and more a matter of fattening and less of growth, until eventually when the animal is fully 'grown' any further increase of live weight can only be due to deposition of fat.

Owing to the variable composition of the body at different stages of development live-weight increase is a very uncertain measure of food-requirement. Thus, in the early stages the 'increase' may contain nearly 80 per cent. of water, whereas in the final stages of fattening this may have fallen to 20 per cent. or less. Furthermore, the dry substance of the 'increase' in the early stages is mainly protein, whilst in the later stages it is mainly fat and therefore more concentrated in character. Measured in terms of energy, 1 lb. of 'increase' in the adult animal is

from four to six times as concentrated as in the very young animal. This is reflected in the familiar practical observation that the quantity of food required to give a particular amount of live-weight increase steadily rises as the animal advances in age.

What we are more particularly concerned to note here is the dominant part played by protein in the earlier stages of growth and its steadily falling significance with advancing age. Clearly, we may expect to find that any chance of influencing growth (and therefore the production of lean tissue) by the liberal supply of protein in the food, will be greatest in the early stages of growth and will tend to disappear when the growth activities of the animal fall behind those devoted to fattening.

If we compare the amounts of protein retained in the body of the growing animal at different live-weights in terms of a common live-weight, we find that the protein storage falls very rapidly in the early months and then more and more slowly as the animal gets older. The amount of food protein that will secure the maximum amount of protein storage in a given live-weight may be regarded as the optimum supply, and any increase beyond this amount is unlikely on the average to produce any appreciable further storage of protein.

The amount of protein retained by the animal clearly represents the minimum amount of digestible protein that must be supplied in its food (in addition to the maintenance protein requirement), but it is very unlikely that this 100 per cent. efficiency of conversion of food protein into body protein can be attained in practice. The nearest approach will be in the young suckling animal living entirely on milk. In other diets the biological value of the protein will be less, and probably ranges in good practical rations from 50 to 80 per cent. of that of milk. In other words it will commonly be necessary to include in the 'production' food 20 to 50 per cent. more digestible protein than is retained by the animal. (In this connexion it is of interest to note that the protein standard commonly used in the rationing of dairy cows requires that the food

shall contain about 70 per cent. more digestible protein than is secreted in the milk produced from it.)

FAT PROBLEMS

The question as to the specific part played by the oils or fats of food in the nutrition of the animal has been the subject of investigation for many years, but still remains in many respects obscure, especially in so far as the application of scientific findings to farm practice is concerned.

The broad facts as to their concentration as sources of energy and their value for the production of animal fats in the body are familiar knowledge, but as to whether they are specifically required for these, or indeed for any other purposes, is less clearly established. Experiments and practical experience have demonstrated that nutritive results approaching the optimum can be obtained under some conditions with rations containing proportions of oil that judged by common farm feeding-practice must be regarded as extremely low. In one of the Harper Adams experiments, for example, a group of pigs on a ration containing not more than 1 per cent. of digestible oil gave just as good growth and carcass quality as a similar group on a ration supplying fully 50 per cent. more digestible oil. A similarly favourable result was obtained in American experiments with a diet containing so little even as 0·5 per cent. of fat. On the other hand, there is evidence from practical observation that, especially when exposed to severe cold, pigs and poultry will consume fat freely if given the chance. The traditional belief of the cattle-feeder in the virtues of oil for giving 'bloom' to his fat beeves may also be quoted.

That there is a minimum fat-requirement, in the case of the rat, at any rate, has been demonstrated in American experiments in which it was found that rats placed upon diets almost entirely devoid of fats developed a scaly condition of the skin, failed to grow, and soon died. Adults on the same diet soon lost the power of reproduction. In each case normal conditions were rapidly restored when a small quantity of an appropriate type (unsaturated) of

oil or fatty acid was added to the diet. There is also evidence that on a low-fat diet the requirement for vitamin B may be increased, and the efficiency of utilization of the carbohydrates of the diet lowered.

In all these experiments which appear to have shown a specific requirement for fat in the food, however, the amounts of fat in the diets have been reduced to a point so far below any proportion that could be attained by the use of the ordinary foods of the farm, that we can practically rule out any risk of shortage of fat in our farm rations that would be so serious as to cause actual injury to the animals.

What for practical purposes is more important to know than the existence of a minimum requirement for fat, is whether there is an optimum level of supply, and if so, where that lies for the different classes of live stock.

On this point the evidence, except in the case of the milch cow, is unfortunately very meagre, and the subject deserves far more attention from investigators than it has hitherto received. The relative richness of the milks of all species in fat raises the presumption that for the early life of the mammal at any rate there is some specific virtue in a high level of fat-supply. The same may also be deduced in the case of the chicken from the richness of the egg-yolk in fat. This 'specific virtue' may, however, amount to no more than the familiar high concentration of energy in the fat. Whatever the real explanation, it is certain that any specific need for fat subsequently diminishes very rapidly to the level represented by the ration with 4–5 per cent. of fat.

That the level of fat-supply in the case of the growing pig is apparently of minor importance, has already been noted, and this may be regarded as a fortunate circumstance since for other reasons to be discussed later it is desirable that the oil-content of pig rations should be kept low.

Food fat and milk secretion

The case of the suckling sow may be different, since there is a certain amount of evidence from work with other

lactating animals that the processes of milk-secretion may be influenced by the supply of digestible fat in the diet. This evidence, which has mainly been obtained in studies with cows, sheep, and goats, indicates that under some conditions, which cannot be precisely defined, changes in the fat-supply in the food are accompanied by changes in the amount of milk secreted, and sometimes a specific effect upon the secretion of milk fat resulting in a rise or fall of the percentage of fat in the milk.

Thus, in experiments with cows at the Cornell Experiment Station the removal of most of the fat from a ration and its replacement by a quantity of starch supplying the same amount of nutritive energy caused a reduction of the milk yield, but no certain effect on the fat-percentage. In this series the amount of fat supplied by the fat-poor ration was actually less than the amount of fat secreted in the milk. In other experiments at Cornell, in which the fat-supply in the ration was not reduced below the amount secreted in the milk, the effects on the milk yield were more uncertain and erratic.

This raises the interesting suggestion that possibly the relation of the amount of fat in the milk to that in the food-supply is the decisive factor that determines the effect, if any, of changes in the fat-content of the ration upon the milk secretion. There is good reason to believe that the production of animal fat from carbohydrates is a more complicated process than that from food fats. It may be, therefore, that when the supply of food fat is very scanty the animal organism, working at full capacity, is unable to manufacture as much product, being called upon to perform the more arduous task of converting carbohydrate into fat, as if a greater proportion of it were coming more easily from an increased supply of food fat.

It will be noted that in these experiments the effect was restricted to the total yield of fat and did not result in any change in the percentage of fat in the milk. Efforts to influence the latter have almost invariably failed, but in the great mass of experimental reports on the subject there are occasional records of positive results which appear to

be valid on critical analysis. The tendency of cod-liver oil to lower the percentage of fat in milk is a case in point, whilst the opposite tendency exercised by palm-kernel and coco-nut oils seems, also, to be adequately demonstrated by Continental experiments and experience. Apart from a few exceptions such as these, however, the main body of experience recorded suggests that a measurable specific influence of the food fat in increasing the secretion of milk fat is obtained only when the fat-supply is well above the upper limits of common farm practice, and further that it is dependent upon the chemical character of the food fat.

Thus, in experiments reported from the University of Minnesota definite increases in the fat-content of milk were produced over short periods by additions of large amounts (1¼–2 lb. daily) of butter fat, lard, tallow, and the oils of linseed, cotton-seed, maize, ground-nuts, soya beans, and coco-nut to the rations of dairy cows. Tests along similar lines in Ireland failed to give confirmation, but this has been supplied in more recent tests at Cambridge. In these tests, in which amounts of oil varying from ½ to 1½ lb. per day were added to normal rations, butter, lard, palm oil, and possibly cotton-seed oil were found to increase butter-fat yield, chiefly by raising the fat-percentage of the milk. Soya-bean, linseed, and whale oils were without effect. Cod-liver oil definitely decreased butter-fat percentage and butter-fat yield. It is remarked, however, that 'experiments with the same oil were not always consistent, and it appears that the effect may vary from cow to cow, and also with the same cow at different times'.

One interesting feature of the Cambridge observations is that the oils which produced favourable results resemble milk fat in having much higher proportions of saturated acids in their fatty acids than the oils that proved ineffective. This may explain, perhaps, why palm-kernel and coco-nut meals in some cases may increase the fat-content of milk whilst linseed and soya meals do not.

The subject clearly needs further investigation, and in

the meantime one cannot prescribe with confidence any enrichment of the cow's ration in oil beyond the level necessary to ensure that the total ration supplies digestible oil approximately equal in amount to that of the fat in the milk secreted. This will generally be assured if the concentrate mixture used contains 4 to 5 per cent. of fat.

Food fat and quality of animal fat

More clear than the evidence as to the effect of food fat upon the quantity of animal fat produced is that as to its influence upon the character of the latter. It is broadly true to say that the food fat tends to impress its general character upon the body fat, milk fat, and even the fat of the egg. This particular effect is notably associated with the unsaturated acids, some of which seem to pass with little change into the body fats.

Fats rich in unsaturated acids are invariably soft in character, and many of them are actually liquid at ordinary temperatures. Such fats (or oils) in the food will, therefore, almost certainly have a softening tendency upon the body fat or butter fat, a property that may constitute an advantage or disadvantage according to circumstances. In the production of beef or mutton, for example, where the natural fat may easily become too hard, the inclusion of food with softening oil may ensure a better-textured fat. In butter-making, a softening effect of the food will commonly mean an advantage in the winter, but a disadvantage in the summer.

In the production of pig fat, on the other hand, where the feeder's problem is to get the fat firm enough, it is obviously desirable to restrict the use of foods with softening oils as much as possible. The problem in its application to meat production is thus clearly one of considerable interest and importance, especially in connexion with bacon-production.

It is complicated by the fact that the fat in the carcass is of two types, which we may describe roughly as 'constitutional' (or metabolic) fat and 'reserve' (or depot) fat respectively. The former is the fat with which the tissues

throughout the body are impregnated, and which is essential for the healthy development of the animal, as distinct from the 'reserve' fat which, as its description implies, is a surplus product stored up under the skin and round some of the organs, which will serve if required to tide the animal over temporary shortages of food.

The 'constitutional' fat has a texture which under normal conditions is characteristic of the particular class of animal, and as a rule is more unsaturated than the reserve fat, but varies at different stages of growth and also with different rates of growth. Thus, in the newly born pig, the fat, which at this stage is mostly 'constitutional', is relatively firm, but tends to become softer during weaning (possibly the effect of the milk fat) and subsequently firmer again. Restricted feeding, or any other factor tending to slow down the growth-rate, will tend to retard this post-weaning hardening tendency. Where the rate of growth is deliberately restricted, therefore, it is all the more important to keep down the proportions of softening oils in the ration.

Generally speaking, the character of the 'constitutional' fat is less affected by changes of diet than that of the reserve fat.

So long as the animal receives more food than it requires for the purposes of maintenance and growth, it will store up part of the surplus in the form of reserve fat. This fat comes partly, and perhaps most readily, from the oil of the food, but in the main from the surplus carbohydrates and proteins. The former fraction of the fat tends to be soft and the latter hard. The texture of the fatty tissues as a whole will thus vary according to the proportions of these two fractions. By increasing the oil-content of the food and reducing the food-supply the proportion of soft to hard body fat laid down will be increased and the whole fat deposit will be softer; by reducing the oil-content of the food and feeding more liberally with starchy foods the amount of soft fat laid down will be reduced and that of hard fat increased. Similarly, where other conditions, such as low temperature, tend to slow down

the rate of growth a less oily ration should be used than may be suitable for conditions of more rapid growth.

Whether a particular oil will have a softening or hardening tendency upon the body fat depends (as found above in the case of butter fat) in great measure upon the extent to which the balance of saturated to unsaturated acids in it approaches to that found in the normal body fat of the animal.

The oils of most of the foods used for the pig are richer in unsaturated acids than normal pig fat and, consequently, are softening in their effects. This applies to the oils of cereals and cereal by-products, fish meal, cod-liver oil, soya meal, and linseed. The oils of coco-nut and palm-kernel meals, on the other hand, are less unsaturated, and therefore less open to objection in this respect.

MINERAL-SUPPLY

The fact that the animal body and animal products contain mineral ingredients, the supply of which must be covered by the food, has been brought into prominence in recent years through the repeated demonstration that many cases of unsatisfactory progress or even ill health under practical farm conditions are directly traceable to mineral deficiencies. The realization of this fact has developed a tendency, however, towards the indiscriminate addition of minerals to rations without any consideration of whether such addition is necessary or desirable. That often such additions have had detrimental effects is certain, these having been due in some cases to the creation of an actual excess of minerals and in others to the establishment of an unfavourable balance between the individual mineral elements. The proper use of mineral supplements can thus clearly only be based upon a knowledge of the mineral content of the foodstuffs included in the ration, and of the mineral requirements of the class of animal to which it is to be given.

The subject is too complex to permit of more than a few of the major features being touched upon here, since a large number of mineral elements enter into the

composition of the animal body. The indispensability of sodium, potassium, calcium, magnesium, iron, phosphorus, sulphur, and chlorine has long been recognized, and to this list modern research has added manganese, copper, zinc, cobalt, and iodine. Varying amounts of each of these elements are lost from the body day by day in the excreta, whilst further loss takes place if products such as milk or eggs are being removed. Should the supplies in the food be inadequate to cover these losses, the deficiency must be made up from the substance of the body itself, a procedure that is clearly undesirable, and if persisted in must inevitably become deleterious to progress and health.

In practice, the effects of a mineral deficiency, unless it is very severe, are apt to develop only slowly, and may therefore escape notice until serious trouble is imminent.

If the shortage is only of brief duration no harm is done, since the animal has a limited power of storing up reserves of minerals during periods of excess supply upon which it can draw when the need arises. This applies particularly to the storage of calcium and phosphorus in the skeleton, which is the great reservoir from which the needs of the body for these two elements are supplied. The extent to which the reserves in the bones can be depleted without injury to the bone is limited, however, and a continuous withdrawal must inevitably lead to bone trouble. In the young, growing animal, where any reserve must be small or non-existent, the bones fail to harden properly and the characteristic lameness or deformations described as 'rickets' soon ensue. In adult animals the bones acquire a brittle character and easily break (osteoporosis). The trouble may be caused by deficiency of either calcium or phosphorus, although the precise effects may differ in points of detail. The problem is not entirely one of the amounts of calcium and phosphorus supplied in the food, since other factors, notably the presence of vitamin D, are essential to ensure proper assimilation and deposition of the minerals.

The familiar need of animals for a supply of salt gives another example of the importance of mineral-supply.

This mineral supplies the essential hydrochloric acid and soda for the digestive juices; it promotes the digestion of fats and proteins, facilitates the circulation of nutrients through the cells of the body tissues, and generally improves the palatability of foods. A less familiar function of the sodium of the salt is that of counteracting the otherwise detrimental effects of any excess of potassium. So important and varied are the functions of salt that a small addition to the ration can rarely be out of place with any class of animal, and is probably actually needed more often than that of any other mineral. In practice, salt requirement probably reaches its highest point in the milk-producing animal, since milk contains appreciable quantities of sodium and chlorine.

Other examples of the fundamental importance of specific mineral elements that may be mentioned are the need for iron along with copper for the production and effective action of the red blood-corpuscles, and that for iodine for the proper working of the thyroid and other important glands.

The practical adjustment of the mineral-supplies in the food to the actual needs of the animal can only be made very roughly, firstly, because of our very imperfect knowledge as to the precise requirements of the animal, and secondly, because of the great variability in mineral content of every foodstuff according to the conditions under which it is produced. The latter difficulty is least in the concentrated foods derived from grains and seeds, and greatest in roots, greenstuffs, and fodders. As a rule we have no alternative but to use average figures, and therefore must be content with a rough estimate of the mineral supplies.

Apart from the actual amounts of each mineral element in the food there are certain other considerations relating to the 'balance' between the individual mineral elements that must not be overlooked.

Firstly, we must take into account that certain of the elements (the metals) are basic in character whilst others are acid. There is much evidence from experimental work in support of the view that any considerable excess of bases

over acids or of acids over bases in the ration is undesirable. In this connexion it is perhaps significant that in the minerals of milk, Nature's food for the young animal, the chemical balance between basic and acidic elements shows almost exact equality.

Secondly, apart from the general relation between total bases and total acids there are interrelations between certain specific elements that should be taken into account. The most important of these are the ratio of calcium to phosphorus and the ratio of potassium to sodium. Mention has already been made of the separate effects of deficiency of calcium or deficiency of phosphorus in causing rickets, or osteoporosis. It must be realized, however, that the two are interdependent, and that the ratio between them may be as important as the actual amounts of each present. A ration may supply liberal amounts of calcium and phosphorus and yet give rise to bone trouble owing to one being too greatly in excess of the other.

The practical importance of the ratio of potassium to sodium lies in the fact that an excess of potassium tends to displace sodium from the body and thus increases the rate of loss of sodium in the urine. A supply of sodium (salt) that would be adequate in the presence of a suitable supply of potassium may thus become inadequate if the latter is in excess, and in these circumstances the supply of sodium in the body is depleted.

For the layman a further complication that arises in attempting to arrive at a correct representation of the balance of the various elements is that the weights (or percentages) of the various elements are not true measures of their chemical reactive powers which determine their effects in the body. Thus 23 parts by weight of sodium are equivalent chemically to 39 parts of potassium, and therefore in a ration containing 0·23 each of sodium and potassium the apparent exact balance (ratio 1 : 1) is misleading, since the true *chemical* balance is

$$\frac{0\cdot23}{23} : \frac{0\cdot23}{39} \text{ or } \frac{1 \text{ (Sodium)}}{0\cdot6 \text{ (Potassium)}}.$$

In other words, the ration instead of having a perfect balance of sodium to potassium (assuming equality to be perfection) actually contains a relative excess of sodium over potassium. The conception of chemical 'equivalent weights' cannot be explained here, and it must suffice to point out that in examining the various 'balances' of the minerals in a ration the percentage figures for the various minerals must be corrected in proportion to the respective 'equivalents' as in the above example.

Lastly, we are faced with the difficulty of knowing what is the correct 'balance' (or ratio) to aim at. On this point it is impossible as yet to get precise guidance, and perhaps the best temporary expedient to adopt is to take the average mineral contents of milk as our standard, which gives us the following ratios (of 'equivalent weights') to aim at:

Acid equivalents	:	Base equivalents	1·1 : 1
Phosphoric acid (P_2O_5)	:	Lime (CaO)	1·5 : 1
Soda (Na_2O)	:	Potash (K_2O)	0·7 : 1

With these standards we may now compare the following ratios in average samples of a few common feeding-stuffs:

	Acid equivalents / *Base equivalents*	*Phosphoric acid* / *Lime*	*Soda* / *Potash*
Wheat	1·4 : 1	8·6 : 1	0·5 : 1
Rye	1·2	8·7	0·3
Barley	1·6	7·1	0·2
Oats	1·9	6·2	0·2
Wheat straw	1·4	0·4	0·4
Barley straw	1·3	0·8	0·3
Oat straw	1·1	0·7	0·4
Meadow hay	0·9	0·8	0·2
Young grass	0·8	0·6	0·2
Mangolds	0·5	2·3	0·8
Swedes	0·7	1·4	0·4
Potatoes	0·6	5·8	0·2
Sugar-beet tops	0·9	0·6	1·0
Linseed cake	0·6	2·1	0·8
Cotton-seed cake	1·0	9·9	0·2
Soya meal	0·8	3·5	0·1
Palm-kernel meal	0·9	4·8	0·4

It will be noted that, judged by the milk standards, the cereal grains all show a distinct excess of acid over base, a very large excess of phosphoric acid over lime, and a marked deficiency of sodium as compared with potassium. Clearly, therefore, they need to be supplemented by lime and salt.

The cereal straws show an excess of total acids, but deficiencies of phosphorus and sodium.

Hay and grass are fairly well balanced as to total bases and acids, with a slight preponderance of base, especially calcium; but are relatively low in sodium. In other words, salt will usually be the only supplement required.

Roots show a surplus of total bases, but a deficiency of calcium relative to phosphorus, and, except in the case of mangolds, a marked deficiency of sodium relative to potassium. Potatoes have a large relative excess of phosphorus, but too little sodium.

Oil-cakes are somewhat variable as between different kinds, but on the whole are fairly well balanced as to total acids and bases, with a slight preponderance of base. They all show a large relative excess of phosphorus, and in most cases a marked deficiency of sodium.

Viewing these groups of foodstuffs as a whole, we see that the main general features are an excess of phosphorus relative to calcium and a deficiency of salt, which, interpreted in terms of practice, means that the mineral supplements most commonly needed will be lime and salt.

THE MEASUREMENT OF FOOD-VALUES

At the beginning of the century the view was commonly held that the nutritive values of rations could be adequately compared in terms of the amounts of digestible protein, fat, and carbohydrates supplied by them, or even more simply in terms of metabolizable energy and digestible protein. Mineral-supply, it was believed, was so rarely deficient in farm feeding-practice that no special attention need be given to it, except perhaps in special cases, such as that of high milk-production, where there was an obvious risk of deficiency of calcium or phos-

phorus. The incidence of other factors, such as palatability and the physical character (bulk) of the ration was not denied, but as these could not be measured little attention was paid to them until well into the new century.

With the year 1905 came the publication of Kellner's classic treatise, in which his 'starch-equivalent' method of assessing production-values was developed, which was based upon 'net energy' instead of metabolizable energy, and represented a marked advance in the application of the energy concept to the assessment of food-values. The same ideas were also being developed in America through the work of Armsby, and under the guise of 'starch equivalents' or 'net-energy values' have subsequently been widely adopted.

That the supply of energy, proteins, and minerals did not complete the tale of factors that influence nutritive value had long been suspected, however, and proof was soon forthcoming in the discovery of the vitamins and other 'accessory' nutritive essentials.

To-day, therefore, we must regard nutritive value as the resultant of the interaction of a large number of factors, all of which must be taken into account if a complete picture of the value of the ration is to be obtained. But any method of assessing food-values which attempted to cover all these factors would be far too complicated to apply in the daily routine of the farm. Perfection being unattainable, we must be content with the best partial measure that is practicable. Having in mind this limited aim, scientific opinion is unanimous that the best single measure of food-values is that furnished by the energy-content of the food, which is derived almost entirely from the carbohydrates, fats, and proteins. It must be kept in mind, however, that the use of this measure postulates that the rations to which it is applied shall be adequate with regard to all other essential factors.

Opinion is divided only as to whether the assessment should be made upon the 'available' energy or the 'net' energy. In Europe, following the lead of Kellner and Armsby, the latter has been almost universally adopted,

but in America opinion has been more divided and has tended in recent years to revert back from the net-energy to the available-energy basis.

Available-energy values are probably more accurate than the corresponding net-energy data and are easier to determine, so that averages for available-energy values of foods are based upon more abundant experimental data than for net-energy values. When foods of similar character are being compared, the one basis is probably as reliable as the other, since the ratio of net to available energy will probably be much the same for each food. But where the foods differ widely in character, especially in the amount and toughness of the 'fibre' present (for example, in a comparison of forage with grain foods), the validity of comparisons on the available-energy basis becomes increasingly doubtful as the disparity in character of the foods increases, and the net-energy basis in such circumstances gives results more in accord with practical experience.

Limitations of starch equivalents

Although the introduction of the starch-equivalent (net-energy) method has undoubtedly effected a considerable improvement in our estimates of comparative food-values, it still rests upon a rather slender basis of experimentally ascertained data, and our estimates remain at best only closer approximations to the truth than were possible with the older methods. The whole trend of modern research on energy-metabolism, moreover, has tended to show that the energy value to the animal of a foodstuff or ration is by no means a fixed entity, but that it may vary according to the conditions under which the food is used, such as the class of animal, kind of production, variation in digestibility, and the 'balance' of the ration.

Kellner's investigations, on which the starch equivalents in common use are mainly based, were carried out entirely with oxen. Their application to the feeding of other classes of live stock is thus beset with very considerable uncertainty, and indeed the later determinations made

with pigs, by Fingerling, led to appreciably higher values for this animal.

In advisory work on rationing we are less often concerned, however, with the *absolute* production-values than with the *relative* values of foods, and provided the digestive powers of two classes of animals for a given range of foods are approximately equal, it is probable that the *relative* production-values of the foods will be much the same for each class of live stock. Such assumption at any rate is our warrant for applying to other classes of fattening live stock the Kellner starch equivalents that were derived exclusively from data on fattening oxen. Support for this assumption has been furnished by practical advisory experience and the evidence of feeding-experiments, which have strengthened the belief that the Kellner starch equivalents furnish a sufficiently reliable basis for a rough control of the rationing of fattening live stock of all classes, and incidentally also of assessing food-requirements for the production of work in the case of the ox or horse.

Much greater uncertainty attaches to the use of the Kellner starch equivalents as measures of the relative values of foods for forms of production other than fattening (and work production), such as growth, milk production, and egg production. In each of these forms of production, protein assumes a dominant role, whereas, as may be noted from the Kellner formula, it is barely equal to starch as a producer of fat. For these forms of production the protein is undoubtedly undervalued in the Kellner formula. For the special case of milk-production, Hansson has drawn up a separate table of starch equivalents based upon the Kellner formula, but crediting the protein with its full energy-value, which is 1·43 times that of starch. This certainly appears to give values more closely in accordance with practical experience in milk-production than the ordinary Kellner starch equivalents, and might perhaps be rather more suitable, also, for application in the cases of growth and egg-production, in which the influence of protein-supply also looms large, but at best it can be no more than a crude device for

effecting some little improvement in our estimates, since the problem is too complicated to admit of any accurate adjustment of the value of the protein by any simple modification of the Kellner formula.

Apart from the protein difficulty there is the further complication that the relative efficiency of utilization of food energy, in general, varies with the form of production in the same class of animal. Thus, in experiments with cattle at the Pennsylvania Institute of Animal Nutrition, it was found that, as compared with the efficiency of utilization for maintenance purposes taken as 1,000, the relative efficiencies for milk-production and for fat-production were 985 and 761 respectively.

Then, again, since the calculation of starch equivalents is based upon the percentage of digestible nutrients the results are bound to be affected by any change in digestibility. Up to moderate levels of food-supply the digestibility of rations by any one class of animal usually remains fairly constant, but at higher levels there is a steady tendency for the digestibility, and therefore the starch equivalent, to fall. At these higher levels, moreover, the efficiency of utilization of the digested energy also tends to fall, whereby the starch equivalent is depressed still further. The starch equivalent of a given mixture of foods cannot be regarded, therefore, as a fixed criterion, but as one which will vary according to the amount of the mixture that is consumed. As production, and therefore food-supply, rises above moderate levels the starch equivalents given in the tables for average conditions should be gradually reduced.

Apart from the factors already discussed, the starch equivalent of a ration varies according to its constitution, and particularly according to the 'balance' of the individual nutrients.

There is evidence that the more nearly balanced the ration the smaller will be the proportion of its energy that will be dissipated as heat, and, consequently, the greater its net-energy value or starch equivalent. A deficiency of one nutrient impairs the efficiency of all others, just as a

defect in a minor part of any other complex mechanism will usually reduce the efficiency of the whole.

This influence of 'balance' has the further effect of making it doubtful whether the total net-energy value of a ration can be arrived at, as is commonly assumed, by adding together the separately ascertained net-energy values of the individual feeding-stuffs of which the ration is composed.

From the considerations outlined above it is clear that net-energy values (or starch equivalents) have their most nearly exact meaning when they are determined for the ration, as a whole, which is completely balanced for the body function in question. But our knowledge is still too imperfect to decide what is a completely balanced ration, having regard to all the qualities that may be concerned with 'completeness'. Moreover, it is clearly impossible to make direct experimental determinations of all the balanced rations that find use in practice.

These difficulties that arise in the application of the net-energy system to the assessment of nutritive values in practice have led some American workers to the view that for the time being the only practicable method is to base the assessment on the available energy ('total digestible nutrients') rather than upon net energy.

This conclusion is, perhaps, unduly pessimistic, since the reversion to the 'digestible nutrients' basis merely avoids one set of difficulties and creates another. It is essentially the method that was used before the introduction of the starch-equivalent basis and, despite the imperfections of the latter, it can hardly be questioned that its general adoption for the control of farm feeding has led to great improvement in the reliability of advisory work and in the development of greater efficiency in farm practice. Although the starch equivalent has proved to be a more variable criterion of production-value than was originally believed, it still remains the best practical estimate we can form from the composition of the food. We must recognize its imperfections and try to reduce them, but it can never be more than a rough guide, often requiring

intelligent adjustment to varying conditions, and offering its chief advantage over other methods when we are comparing foodstuffs of widely differing nutritive character.

ACCESSORY FACTORS IN NUTRITION

The outstanding triumph of nutrition science in the present century has been the discovery of the importance of a number of nutritive essentials (vitamins, hormones, &c.) which, though required in only very minute proportions, may exercise nevertheless a very profound influence upon the general metabolism and health of the animal.

In the opening years of the century food was regarded chiefly as the source of the material necessary for the constructive processes going on in the body and of the energy required to support its metabolic activities. Subject to the satisfaction of postulates as to the palatability and general suitability of the ration, these requirements were regarded as being fully covered by the supplies of digestible proteins, minerals, fats, and carbohydrates.

Observations had certainly not been lacking for many years back, especially in the study of disease, that seemed to indicate the existence of other essential factors. Very early Chinese records mention the prevalence of night-blindness (now known to be caused by lack of vitamin A), and cite as specifics against the trouble various vegetable products that now can be shown to be specially rich in the necessary vitamin. More familiar instances are the 200-year-old knowledge of the virtues of lime-juice as a preventive of scurvy, and the use of cod-liver oil as a specific against rickets long before the real causes of this trouble were understood.

Parallel with this accumulation of evidence of the existence of accessory essentials from the study of disease, there had developed also indications that the requirements for growth in the young animal could not be met entirely by the basic nutrients. As far back as 1881, a Swiss investigator, Lunin, reported the failure of mice to grow on an artificial diet of milk proteins, lactose, and

milk ash, but it was not until twenty-five years later that conclusive proof of the soundness of these observations was furnished by the classic experiments of Hopkins, at Cambridge. His demonstration of the necessity of 'accessory food factors' for the effective functioning of the vital processes was then soon rounded off by the definite proof of the existence and specific physiological function of the growth factor (Vitamin A) by American workers.

By this time, also, the proofs had been completed that beriberi and scurvy were caused by the absence of specific chemical factors from the diet, so that clearly a whole new field of work had been opened up for the nutrition investigator. Since the precise chemical character of these 'factors' was at the time entirely unknown, and they could not therefore be classified on a chemical basis, they were simply grouped together as 'accessory factors', a rather cumbrous description, which soon gave way to the simpler term 'vitamins'. Subsequent isolation and identification of some of the vitamins has revealed that they do not belong to any one chemical group, and certainly are not 'amines', but from the physiological and nutritional standpoints it has proved convenient to retain the original conception of the vitamins as a special group. For similar reasons the terminology devised for the individual vitamins by allotting different letters to them has been retained, although in many cases a more precise chemical nomenclature could now be used.

The profound impression created by the early vitamin discoveries is seen in the rapid subsequent development of vitamin research, on which to-day probably more investigators are engaged than on any other class of nutrition problem.

It is the common experience in the investigation of scientific problems that the deeper they are probed the more complex they are found to be; such also has been the experience in the development of the vitamin concept. The original 'growth factor', or Vitamin A, of Hopkins was soon proved to be a complex of two vitamins or possibly more, and it became necessary to discriminate

between vitamin A, with its more generalized effect upon the growth processes, and vitamin D, with its specific effects upon the growth of bone. Similarly, for the original concept of a simple vitamin B we must now substitute the concept of a 'vitamin B complex' in which the anti-beriberi vitamin, the original B, is the B_1 factor, the water-soluble growth-promoting vitamin the B_2 factor, and so on. A similar complexity has been revealed in the C group, and the vitamin D group is said to include at least ten different 'strains'.

A subject of such complexity obviously does not permit of concise summary here, and for details of present knowledge of the extent and varied physiological significance of the vitamin groups the reader must be referred to one or other of the various monographs on the subject now available. It must suffice here to make a few observations on the practical significance of the vitamins in modern live-stock husbandry.

This is primarily determined by the system of management practised, and the broad principle may be laid down that the more this system deviates from the natural open-air life of the wild animal the more necessary does it become to have regard to the supply of vitamins in the diet. The outdoor-living animal, subsisting on natural foods, such as grass and other greenstuffs, roots, seeds, &c., will commonly secure an adequate supply of all the necessary vitamins, especially throughout the period of the year in which active plant growth persists. If the food-supply during this period is abundant it will probably store up a reserve of vitamins that will carry it through the greater part, if not the whole, of the winter. Similarly, for live stock living wholly or partly indoors the risk of vitamin shortage will be less where natural foods such as the above still form a substantial part of the diet, than where the ration consists wholly or mainly of 'artificial' foods. The risk will be less, for example, with housed cattle than with housed pigs. Viewed from this angle one would expect to find—and one does find—that the practical risks are greatest with pigs and poultry kept entirely

indoors. Young cattle may run some risk of shortage in winter if the hay-supply is poor and no greenstuff is available. Under similar conditions the milk yielded by dairy cows is apt to be well below the average in vitamin-content, but no measurable effect upon the health of the cow has been demonstrated. Our systems of sheep management are such as to render vitamin-deficiency in their case very improbable, and no clear example has yet been recorded.

Of the individual vitamins, those most frequently found to be deficient on the farm are A_1, B_2, and D. Vitamin C (anti-scorbutic) seems to be of relatively little importance to farm animals, and although the widespread incidence of sterility in breeding-stock suggests that deficiency of Vitamin E (anti-sterility) may be a contributory factor, little valid evidence of this has yet been obtained.

The supply of the B-vitamins does not often cause any concern on the farm, except in the case of intensively kept poultry, where shortage of vitamin B_2 may arise unless the ration is properly constituted to avoid it. Failing a good supply of fresh greenstuff the best preventive measure is the addition of a little yeast to the ration.

Commonest of all shortages is that of vitamin A, and this also turns largely upon the amount and quality of greenstuff supplied. Fresh greenstuff from summer pasture will usually contain a relatively high proportion of carotene, the coloured principle out of which vitamin A is produced in the animal. When the greenstuff is rapidly dried by artificial heat there is little destruction of the carotene, but if made into hay under unfavourable conditions a large proportion of it may disappear. In the latter case the hay is obviously a poor and unreliable source of the vitamin. Where greenstuff is not available, or is low in carotene, the supply of vitamin A can best be safeguarded by the addition of a little cod-liver oil to the ration, which will usually also make good any deficiency of vitamin D.

Vitamin D is unique, however, among the vitamins, in that it can be produced directly in the animal's body by

exposure to ultra-violet radiation of suitable frequency. It may also be produced in many foods by similar exposure. This effect of ultra-violet radiation is now common knowledge, and its original discovery marked a great advance in the therapeutic treatment of rickets. It also points the way to the stock-feeder as to the simplest safeguard of his young stock against rickets being to ensure for them a reasonable degree of exposure to solar radiation, either outdoors or, if this is impracticable, by providing his buildings with windows that either can be thrown wide open in suitable weather, or are glazed with a glass that is permeable by the required ultra-violet rays.

Reference has been made to the fact that the precise chemical character of several of the vitamins has now been ascertained, so that it has become possible to manufacture them by artificial means, and various 'synthetic vitamins' and 'vitamin concentrates' are now on the market. If these are used intelligently, and only in cases of actual vitamin shortage, they may be made a very convenient form of vitamin dosage, but the warning must be repeated that an excess of vitamin may be harmful, and there is no evidence that the normal, healthy animal, receiving a ration that is obviously adequate in vitamins, is likely to derive any benefit from a further supply.

A further development in the field of knowledge of accessory factors bearing upon animal metabolism is the increase of knowledge of the activities of the glands of inner secretion, such as the pituitary and the thyroid glands. It is now known that these glands exercise controlling influences upon some of the most fundamental vital functions, such as the processes of reproduction, growth, and milk-secretion, and that this control is exercised through specific chemical agents, or hormones. Examples of these are the thyroxin of the thyroid gland which influences the growth processes, and prolactin (or galactin) from the pituitary gland which is required to initiate secretory activity in the mammary gland. These hormones do not necessarily come direct from the food, but their production in the body may be influenced by the

food-supply, and in some cases this influence is direct, as in that of the provision of the iodine required for the synthesis of thyroxin.

Hormonal research is but in its earliest stages as yet, but it has already produced results that reveal the far-reaching influence it may have upon future practice in animal husbandry.

Lastly, just as in the field of organic nutrients modern research has brought out the importance of many ingredients present in only very small proportions, so also in the field of mineral metabolism many of the 'minor' elements are proving to have a significance hitherto unsuspected. Some, such as manganese, copper, and cobalt, are apparently essential; others such as nickel, arsenic, boron, and bromine have been identified in various tissues, but the question is still open as to whether they are essential for any specific body function.

THE EVOLUTION OF MILK-PRODUCTION

By JAMES MACKINTOSH

TO the student of British Agriculture one of the most significant features of recent times has been the development of milk-production.

During the latter part of the nineteenth century the sale of milk from farms to meet the needs of an ever-growing urban population was gradually replacing the manufacture of cheese and butter in many districts, and at the dawn of the twentieth century dairying had become one of the chief branches of agriculture. This development has continued steadily, and at the present time milk represents some 24 per cent. of the total value of agricultural produce sold off the farms in England and Wales and is the largest single item.

It is the object of this essay to give an account of the development of dairy science and its application to the practice of milk-production, together with other improvements, during the last forty years, and for this purpose it appears desirable to consider in succession three separate periods. A brief description of the prevailing conditions during the first will enable the progress made later to be more fully appreciated.

The first period is from 1900 to about 1912, when the conditions of the industry were generally similar to those of previous decades, with the exception that there was a growing realization of the need for additional facilities for education and research to help in the solution of the many problems which confronted both milk producers and distributors.

The second period extends from 1912 to 1933, when, apart from the years of the War, there was rapid development in scientific research and in the means whereby its lessons were conveyed to those engaged in the industry. This development only became possible through schemes financed to a large extent by the Development and Road Improvement Fund Act of 1909.

The third period dates from 1933, when a change in the fiscal policy of the country, and the formation of a milk marketing scheme under the Marketing Act of 1931, created entirely new conditions with new problems and, fortunately, new assistance in the attempts to find solutions.

FIRST PERIOD, 1900–12

Existing conditions. At the beginning of the twentieth century the methods generally adopted in the production of milk showed but little advance on those in use twenty-five to thirty years earlier. Cows were often housed in buildings originally erected for the accommodation of other stock or crops, converted more or less efficiently into cowsheds; hand milking was almost universal; the milk was strained, usually through a wire-gauze strainer, and cooled by the corrugated type of cooler with water inside, very similar to that brought out by Lawrence in the 1860s; it was conveyed in large churns of seventeen gallons capacity, usually transported to the station in a horse-drawn vehicle, and, in warm weather, the wastage by souring was often a source of serious loss and worry. On a number of farms milking-machines had been installed and milk-recording was practised by a few progressive herd-owners.

The making of cheese and butter on the farms was still practised, though to a gradually diminishing extent. Cheese was made in the counties and districts traditionally devoted to this industry, such as Cheshire, Salop, Somerset, and Dorset. Butter was made on many farms in districts more remote from towns and railways, and it was commonly associated with the rearing of store stock.

In 1892 Rew studied the production and consumption of milk and came to the conclusion that two-thirds of the total output was sold for direct consumption and one-third was used for the manufacture of dairy produce. This statement attracted some attention to the fact that the majority of dairy farmers had changed their mode of business, but the significance of this change was not realized by the representative agricultural societies and

county authorities who had sponsored the pioneer educational activities in dairying. Attention was still concentrated on giving instruction in butter- and cheese-making, to the neglect of that phase of the industry which was the main source of income. It will be readily understood that, where the milk was made into produce on the farm and this produce had to be kept for varying lengths of time, problems had arisen in the management of the milk, in the process of cheese-making, and in the lack of keeping-quality and attractive flavour in the butter and cheese, which called for investigation and for the dissemination of knowledge that would lead to the production of better and more uniform products.

Education and research. The British Dairy Farmers' Association was the first body to provide a centre for practical and scientific instruction in dairying. In 1888 the British Dairy Institute was established at Aylesbury, and in 1896, in order that the students might obtain better instruction in science, it was moved to Reading and placed under the management of a committee representing the Association and the University College (now the University) of Reading. In 1910 a new Institute, with better equipment and accommodation for a larger number of students, was erected. Since its establishment the British Dairy Institute has been the leading centre for dairy education in England and Wales.

Instruction in butter and cheese-making was also given during this period at itinerant dairy schools in a considerable number of counties and at recently equipped centres such as the Midland Dairy Institute (now the Midland Agricultural and Dairy College), the Royal Agricultural College, Cirencester, and the Eastern Counties Dairy Institute, Ipswich.

These early developments, however, were concerned almost entirely with teaching, and the only instance of definite research work designed to assist the industry was the series of investigations carried out by Lloyd, in Somerset, from 1891 to 1898. Lloyd's work was financed by the Board of Agriculture and the Bath and West and

Southern Counties Society, and was conducted each year at a different cheese-making farm in the county. The first object of his experiments was 'the formulating of a complete scheme of investigation of the science which underlies the existing practice of the best cheese-makers', and he was also asked to ascertain 'the causes of defects in cheese-making from quality of milk, &c.'

Lloyd's report to the Board in 1899 has been almost forgotten, but well deserves mention in this article. One of his most significant remarks is to the effect that the promoters of the investigation believed that the problems to be solved were mainly of a chemical nature, but the facts ascertained by the observations soon showed that cheese-making had to deal also 'to a large extent with bacteriological questions'. That one chemist, working almost single-handed, should have been asked to tackle such a subject indicated, perhaps, a sublime faith in the potentialities of science, and certainly illustrated the need for the wider facilities which, to some extent at least, have been provided during recent years.

Legislation and its influence on research. Another instance of the slow recognition of the growth and importance of the sale of milk for direct consumption is that legislation directly applicable to milk-production only became operative about 1878, and at the beginning of this century the chief legal enactment affecting the conditions of production was the Dairies, Cowsheds and Milkshops Order of 1885. The administration of this order was placed in the hands of the local authorities, and, while some took their responsibilities seriously, others did not. The Model Regulations issued by the Local Government Board (now the Ministry of Health) for the guidance of local authorities were seldom adopted, but they had a definite educational value as they set up a standard with which progressive milk-producers endeavoured to comply. Increased attention, however, was being given by medical officers of health and others to the cleanliness and wholesomeness of the milk-supply, and investigations by bacteriological methods were adding to our knowledge of the

cause of souring and of various taints, and also of the extent to which milk might be the carrier of infectious diseases.

In 1907–8, a careful study of the condition of the milk-supply of the East and West Ridings of Yorkshire was made by Dr. J. Orr. This investigation was the first on a large scale in England in which an attempt was made to trace the sources of the bacteriological contamination of milk. Its object was twofold—to determine (*a*) whether the milk-producer, the distributor, or the consumer was mainly responsible for the contamination of milk, and (*b*) the chief sources and nature of the contamination at the cowshed, during railway transit, at the retailer's premises, and at the consumer's house. Orr's conclusions were that the greatest amount of contamination occurred at the farm from improperly cleansed milk-utensils and the dirty udders of cows (the former were the chief sources in the summer and the latter in the winter) and that additional contamination was contributed by improper conditions of transport, dirty and faulty cans, and carelessness at the retailer's premises or in the course of delivery. A wide range of suggestions for improvement at all stages was made, and the imposition of maximum standards for bacteriological content and sediment was advocated. This report confirmed the views of many engaged in the handling of milk, that the practice of cleanliness at the farm, which the cheese- and butter-maker had found to be essential to the manufacture of a good dairy produce, had been largely neglected in the production of milk for sale.

Another important legal enactment came into force in 1901—the Sale of Milk Regulations, made under the Sale of Foods and Drugs Act, 1899. These regulations, which are still operative, state that where a sample of milk, not being sold as skimmed or separated or condensed milk, contains less than 3 per cent. of fat or less than 8·5 per cent. of solids other than fat, it shall be presumed, until the contrary is proved, that it be not genuine. Contemporary records show that adulteration of milk was frequent previous to the issuing of the above order, and that, although subject to criticism in some respects, it had

a definitely beneficial effect on the quality of milk offered for sale. In another respect the regulations exercised a marked influence. The need for keeping milk 'up to the standard' stimulated producers to study much more closely than hitherto the different circumstances influencing the composition of milk and encouraged agricultural educationists who had time for research to undertake investigations on this subject. At Leeds, from 1900 to 1906, Ingle, and later Crowther, made careful studies of the chief factors influencing the quantity and quality of milk. Their work showed clearly that for individual cows, not only the yield, but also the fat-percentage—and to a less extent, the solids-other-than-fat—was subject to great variation; that where the interval between milkings exceeded twelve hours, the milk obtained after the longer interval was greater in quantity but poorer in fat and that the mixed morning milk of a dairy shorthorn herd might often contain less than 3 per cent. of fat during summer or early autumn. They also showed, contrary to widely held opinions, that when cows received liberal rations, variations in the nature of the food supplied had little influence on the quantity or quality of the milk produced. From 1903 onwards, similar work was carried out by Gilchrist, Bryner Jones, Walker, and Collins, at Newcastle. These investigations were most helpful in assisting milk-producers to understand the causes which contributed to the variation in the composition of milk and the precautions which should be taken to maintain milk above the so-called standard.

Changes in practice and outlook. During this period, also, there was an increase in the attention given to the results of research into dairying and dairy-farming subjects in other countries. On the one hand, summaries of the results obtained in experiments carried out at American and Continental research stations appeared in the chief agricultural journals, and, on the other, commercial firms interested in milk production and handling introduced new and improved types of dairy apparatus. Towards the end of the previous century, factories had been established

in several dairying districts to deal with locally produced milk by making it into cheese, butter, condensed milk, or other dairy products in the summer, and by brine cooling or pasteurizing enabling it to be transported in a sweet condition to the large cities during the winter. The adoption in Scotland in 1903, by societies of farmers, of a system of recording the yield of, and the percentage of fat in, the milk of individual cows, attracted attention, and several agricultural colleges and county councils in England organized similar local schemes; in a few instances special attention was given to the rations which the cows received and the reports published on this work paved the way for the notable later developments in this aspect of herd management.

Although during the early years of this century the record of progress in the scientific study of milk production and management is meagre, and the application of the proved results of research was slow and irregular, there was a steady development of agricultural opinion and, indeed, of public opinion generally, that there should be provided greater facilities for research and education in all branches of agriculture. In certain subjects, such as the study of the soil and of manures, the work at Rothamsted, begun by Lawes and Gilbert and so ably carried on by Sir Daniel Hall, had proved of incalculable practical value and had gained international renown, but there had been no scheme for the development of research on a national scale and in relation to the different branches of farming. Private, college, or county enterprise was not sufficient, and assistance from the national exchequer was essential to provide ways and means. In 1909 the Development and Road Improvement Funds Act made provision for much larger sums of money to be spent on agricultural education and research, and laid the foundation for the marked progress which has since taken place.

SECOND PERIOD, 1912–33

Establishment of a Research Institute. In March 1911 a report was issued by the Development Commission, of

which Hall was a member, outlining the scheme for the encouragement of agricultural research in general. In this scheme agricultural science was divided into eleven main branches, and for each branch provision was to be made for systematic research at one or two institutions.

Dairying was specified as one of these main branches and, as no institution in existence was equipped for this work, a new one had to be created. Reading was chosen as the most suitable centre, and Hall himself has briefly recounted the first steps towards the creation of the Institute. In a preface to a monograph issued in 1924 he wrote: 'This Institute dates back to 1911, for it was on 30th September in that year that the then Board of Agriculture received a memorandum urging the suitability of Reading as a centre for dairying research and in reply indicated its willingness to make a two-thirds contribution up to £2,500 per annum towards the cost of such an Institute.'

The new Institute began its active career in the autumn of 1912 with a research chemist (Golding) and a research bacteriologist (Stenhouse Williams) as the nucleus of a staff. Work was at once commenced on some problems, which, as it happened, were broadly typical of the future field.

Milk-production was represented by the study of the construction and ease of cleansing of some twelve types of milking-machines taking part in a trial organized by the Royal Agricultural Society, at Bishop Auckland; the handling of milk provided the problem of ventilated or unventilated churns for rail transport (and Hall again supplies the information that the first payment authorized by the Ministry to the Institute was one of £7 on milk churns, milk, sterilizing, &c., in connexion with this investigation); cheese-making was represented by experiments on the preparation of home-made rennet and on the causes of discoloration of Stilton cheese.

Progress, of course, was seriously interrupted by the War. In 1919, when it was again possible to devote time to the problems of peace, a Dairy Husbandry department,

under the writer, was added to the existing departments of Chemistry and Bacteriology, and steps were taken to provide the Institute with a farm and reasonably adequate laboratories. These were found at Shinfield, in 1920, and from 1923 to the present time the staff of the Institute, now the National Institute for Research in Dairying, have carried out work on many problems and have made many helpful contributions to the science and practice of dairying.

An attempt will now be made to give, under appropriate headings, a concise account of the main lines of progress in respect of milk-production, including some of the work of the Institute, as well as developments which originated in other quarters.

Dairy-herd management. The aims of the Institute in the formation of a dairy herd were, firstly, to have milk for the research work and, secondly, to build up a home-bred herd possessing good milking-qualities, of good breed type, with good udders and free from tuberculosis. Two breeds—Dairy Shorthorn and Guernsey—were chosen, and since 1921 careful records on many points of importance have been kept. The study of these, in addition to the experiments, has enabled definite contributions to be made to the knowledge of herd management.

Milk and fat recording. The practice of daily milk recording was adopted as soon as the nucleus of a dairy herd was obtained, and samples of milk from each cow were tested on three successive days in each month for the percentage of fat and solids-not-fat. The information thus obtained was utilized to assist in the development and amendment of the official scheme of milk recording, which had been inaugurated by the Ministry as part of Live Stock Improvement Schemes under the Development Act.

From certain aspects of milk-production the formulation, in 1913, of an official scheme to assist farmers to obtain records of the milk-yields of individual cows was one of the most important movements of this century.

For many years a small number of progressive herd-owners, and later, several agricultural colleges and county councils, had practised and advocated systematic milk recording, but until the inauguration of an official scheme, whereby societies of farmers who agreed to abide by the Ministry's rules and regulations received financial assistance, very little progress was made. During the period of the War advance was almost impossible, but since 1919 societies have been formed to operate in every county in England and Wales. Taking the country as a whole official milk recording has not been enthusiastically adopted, for at the present time records are being taken of only some 6 per cent. of the cows. In some counties, however, where the production of milk for sale is the sole form of dairy farming, from 25 to 29 per cent. of the cows are officially recorded.

When the scheme was first introduced stress was laid on the quantity rather than on the quality of the milk, but in the course of time it was realized that the selection of cows and bulls on the basis of yields alone would tend definitely to lower the average fat-content in the milk. The detailed information collected in the Research Institute's herd provided a basis for the construction of a scheme whereby the average fat-content in the milk of individual cows over a lactation or other period could be calculated with reasonable accuracy, and, through the agency of the Central Council of Milk Recording Societies, the Ministry incorporated the necessary additional regulations in the official scheme in 1933.

Interpretation of milk records. The practice of milk recording supplies accurate information on the quantity of milk yielded by a cow in any given period of time, but experience has shown that the yield is affected by a variety of conditions and that careful study is necessary to interpret the effect of these conditions accurately. Much valuable work on this subject was done by Sanders, and his investigations enabled him to arrive at 'correction factors' for yields made under varying conditions. The age of the cow exerts the greatest influence on her yield, and Sanders has

recommended that, to estimate the lactation yield a young cow may be expected to give at maturity, 30 per cent. should be added to the first lactation yield, 18 per cent. to the second, 10 per cent. to the third, and 4 per cent. to the fourth. He also studied the effect of calving at different seasons of the year, and recommended the deduction of 3–5 per cent. from the lactation yield of winter calvers and the addition of 3–7 per cent. to the yield of summer calvers to arrive at a normal yield. Correction factors have also been ascertained for abnormal dry periods before calving and abnormal periods between calving and service, but their use leads to great complexity and Hunter-Smith and Edwards conclude that they need not be used. Correction factors have not been adopted to any extent commercially, but the investigations on these and related points have contributed materially to our knowledge of the effect of different circumstances on the lactation yields of cows, and on the interpretation of the records quoted in sale catalogues and elsewhere.

Progeny recording. After some years the records of production and breeding in the Shinfield herd became sufficiently abundant to demonstrate the effect which the various stock bulls had had on the type, and the yield and quality of the milk, of their progeny: one bull had daughters which matured slowly according to the breed standards, but they had good udders and ultimately gave good yields of milk of satisfactory fat-content; another bull had quicker-maturing daughters, which also gave good yields with a good fat-percentage, but a large proportion had udders which became pendulous and liable to injury at an early age; a third bull produced daughters, some of which were excellent in every respect and some were very unsatisfactory milkers, while a fourth bull produced daughters whose milk-yields were good but the fat-percentage fell definitely below that of their dams.

The importance of judging the breeding value of a bull by the merits of his progeny was recognized by the pioneer improvers of British live stock in the eighteenth century, but until milk and fat recording was practised.

the true merits of the daughters of a dairy bull, and therefore of the bull himself, could not be assessed. In 1920 the writer illustrated this important point by the use of records from the herd owned by the University of Reading, and, after the subject had been given greater publicity by Hammond, Edwards, Buchanan Smith, and Hunter-Smith, the Ministry introduced a scheme for the recording of the progeny of dairy bulls, to be operated through milk-recording societies. The scheme is still in its infancy, but its potential value in the breeding of better dairy stock cannot be overestimated.

Calf-rearing. Methods of calf-rearing have also been closely studied with special reference to the rearing of calves on farms where it is desired to sell as much milk as possible. By a study of the composition of milk and of other foods, by free choice and other methods of experiment, a method was ultimately evolved whereby calves could be reared satisfactorily on not more than 40 gallons of new milk, supplemented, after cud-chewing had commenced, by hay, dry concentrates, and water. Later experiments showed that by the use of dried milk and a little cod-liver oil the quantity of new milk needed could be reduced to about 20 gallons. The adoption of this method has simplified and cheapened calf-rearing in many districts, and, with variations, has gained additional popularity in recent years in Attested herds and on farms producing Tuberculin Tested milk where the bonuses obtainable encouraged producers to increase sales to the maximum.

Rearing of dairy heifers. Methods of feeding and rearing of dairy heifers have also been studied at the Institute, and the experiments have shown that the standard quantities of nutrients recommended by American investigators for young stock were suitable for English conditions. Records of the live weight at frequent intervals from birth to maturity, with measurements of the height at the withers, the heart girth, and the length of body, were also taken from a large number of animals. These have been tabulated for different ages to show the growth of young

dairy stock under normal conditions of feeding and management and to afford standards of comparison for experimental work.

Protein requirements of dairy cows. Recently a large-scale experiment has been conducted on the protein requirements for milk-production. The co-operation of farmers in the neighbouring counties was obtained, and in two successive years 500 and 900 cows were included. The results have shown clearly that the standard quantity of 0·6 lb. protein equivalent per gallon of milk can be reduced by 20 per cent. to about 0·5 lb. without affecting the condition of the cows or the yield and quality of the milk.

Machine milking. During the latter part of the last century commentators on the increase of milk-production for sale remarked on the growing scarcity of good hand milkers and hoped that some day it would be possible to milk cows by mechanical means. From 1880 onwards milking-machines frequently appeared in the lists of new inventions for agricultural purposes, and trials were arranged by the Royal Agricultural Society in 1882, 1900, and again in 1913. By this time a considerable number were installed on farms with varying degrees of success; during the War many more were purchased, and though a proportion of these were discarded when labour became more plentiful, mechanical milking had proved its usefulness. But although good milk-yields could be obtained there was evidence that the keeping-quality of the milk frequently suffered, and no detailed study had been made of the causes.

In 1925, a milking-machine was installed at Shinfield and careful observations were made for some two years. Two defects—one of erection plus management and one of instructions for cleansing—were ultimately found, which, when corrected, enabled milk of uniform cleanliness and high keeping-quality to be produced. The defect of erection lay in placing the overhead vacuum pipe-line in a horizontal position with the vacuum supply taps emerging from the bottom of the pipe-line; water,

heavily contaminated with bacteria, accumulated in the pipe-line and at intervals passed downwards through the valves on the lids into the milk. The defect in cleansing arose from the makers' relying on washing only without requiring sterilization by steam. When the pipe-line was erected in sections with a slight slope and with a drainage-valve at the bottom, the vacuum taps inserted in the upper half, and air drawn through before milking to ensure dryness, no further contamination occurred from this source. When the rubber parts which came in contact with the milk were thoroughly washed and sterilized by steam, this defect also was rectified. Makers of milking-machines quickly adopted the new procedure in erection and cleansing, and the success which has attended the use of milking-machines in recent years is in no small measure due to the work and advice of the Institute.

Comparisons have also been made between hand and machine milking in their influence on milk-yields. It was found that the yields by machine milking were some 50 gallons lower than by hand on cows and heifers averaging 700 gallons. No measurable difference was found in the composition of the milk obtained by the respective methods.

Open-air milk-production. In some of the southern counties in England during this period there was a development in the management of dairy herds which attracted much attention. Hosier demonstrated that milk could be produced efficiently and economically without cowsheds and with much less labour, where the conditions of soil and climate permitted the herd of cows to be kept out of doors day and night at all seasons of the year. In many parts of England, cows had been kept out day and night at all seasons but were milked indoors, and in other parts cows had been milked in the field during the summer, but the new system combined these two customs and added new methods. The essential features of the system are the maintenance of a large herd of milking heifers or cows—usually some 60–70 in number—on a large range of dry land or down pasture at all seasons, and the milking of the

herd in relays of 6 or 8 by a milking-machine, of the releaser or auto-recorder type, built into a wooden structure or 'bail' which can be moved at will to a fresh site in the field. Concentrates can be given to each cow at milking-time, and hay, roots, or other green foods can be given on the pasture when necessary. Experience and careful investigations have shown that the system lessens the cost of milk-production by the saving in the cost of housing, in the labour of cleaning cowsheds, in the removal of manure, and in milking. The system has been adopted on wide areas of suitable land, and in other instances, particularly where the cowsheds were unsatisfactory, the bail structure has been erected at the homestead for the milking of the cows, whether these are accommodated in the fields or in yards.

Additional herd-management subjects which have been studied at the Institute include the maintenance of a herd free from tuberculosis, the control of contagious abortion and mastitis, and the use of artificial insemination, based on the work of Hammond and Walton, as a means of making fuller use of proved bulls. The records kept and the experience gained have provided data which has proved invaluable as a basis for advice and for testing and evaluating many of the new methods, practices, and opinions which are placed before dairy farmers from time to time.

THE COMPOSITION AND SECRETION OF MILK

The work of Ingle, Crowther, and others already referred to laid a sound foundation for our knowledge of the circumstances influencing the composition of milk; later investigations have confirmed the earlier conclusions and added to our knowledge on certain points regarding the fat-content, but more particularly with reference to the variations in the solids-not-fat.

Fat-content. More accurate information is now available from independent sources regarding the average fat-content in the milk of the various dairy breeds. The most reliable figures are those obtained for large numbers of

cows through the Ministry's Milk Recording and Fat Testing Scheme, and these show the following range in percentages over three successive years: Jersey, 4·86–5·01; Guernsey, 4·61–4·64; Ayrshire, 3·71–3·78; Red Poll, 3·62–3·71; Shorthorn, 3·56–3·61; Lincoln Red, 3·54–3·62; and British Friesian, 3·26–3·31.

Numerous experiments have been conducted on the effect of feeding on the fat-percentage, and the conclusion by Ingle and Crowther already mentioned has not been seriously contested. Golding, however, has shown that addition of over 4 oz. of cod-liver oil to the cow's ration causes a marked depression in the percentage of fat, and work by others indicates that the fat-content may be increased by inducing a cow to eat a liberal but uneconomic quantity of butter.

Solids-not-fat content. After the introduction of the Sale of Milk Regulations in 1901, attention was directed mainly to the fat-content of milk and the wide fluctuations which were found to occur under normal and abnormal conditions. The solids-not-fat content was but little studied, as comparatively few samples were found to fall below the 8·5 per cent. standard. More recently, Cranfield produced evidence that genuine mixed milk from herds was not infrequently below the standard, and special attention has since been given to this subject. The data collected from the Shinfield Institute herd over a ten-year period had been studied by Bartlett, and he has found that the stage of lactation, the interval between milkings, the efficiency of milking and of feeding do not affect the solids-not-fat percentage except in so far as this is influenced by changes in the fat-percentage. The chief cause of variation was found to be the individuality of the cow, and more recent work indicates that when mastitis is present in the udder, the percentage of solids-not-fat is lowered. Other investigations have shown that the solids-not-fat content falls appreciably during a hot dry season; to what extent this fall is associated with the burning-up of pasture is not yet known. These investigations have shown the most probable causes of low solids-not-fat, but they have not

indicated remedies beyond the selection of cows which have sound udders and naturally produce milk of satisfactory quality.

The secretion of milk. It is only in recent years that research work designed to discover how milk is made in the cow's udder has been undertaken in this country, and the chief workers have been the staff of the Physiology Department at Shinfield. Experimental work in other countries had shown that the mammary glands were stimulated into activity by internal secretions or hormones elaborated in the ductless or endocrine glands. At Shinfield, work has been begun on the hormonal factors which appear to control the chemical composition of milk. Thyroxine, the hormone from the thyroid gland, has been shown to increase the yield of cows in declining lactation and to increase the percentages of fat and solids-not-fat. Other hormones have been found to have characteristic effects and, although the investigations are in little more than the initial stages, there is no doubt that in the course of time new knowledge of great value will be obtained on the formation of milk, with indications, perhaps, of how, under experimental conditions, the chemical composition may be controlled.

HYGIENIC QUALITY OF MILK

Reference has already been made to the pioneer work of Orr on this subject, and the need for a greater appreciation of the importance of cleanliness in the production and handling of milk, and some of the most valuable and effective research and educational work of this century comes under this heading.

Graded milk. Before 1912, a small group of 'clean milk' producers, of whom Buckley was the best known, were striving by example and precept to get better methods adopted. During the War, the control of milk prices gave rise to the problem whether permission to charge a price above the normal should be granted to those who were producing specially clean milk from tubercle-free herds. Such permission was granted by the Food Controller

under certain conditions and, when the Ministry of Food ceased to function, the Ministry of Health, by the introduction of the Milk (Special Designations) Orders, 1922 and 1923, gave official recognition to the grading of milk; the issue of licences to use the grade-names depended on compliance by the applicant with specified conditions as to the health of his herd and the bacteriological condition of its milk. These orders also introduced a new feature into milk legislation in that no producer was compelled to comply with the conditions unless he chose to apply for a licence, and failure to comply did not lead to prosecution but only to a refusal or cancellation of a licence.

The grades of milk specified in the 1923 Order were 'Certified', 'Grade A (Tuberculin Tested)', 'Grade A', and 'Pasteurized', and the first three were the primary concern of the producer. The number of licences issued increased slowly because the demand for these grades was small, but the introduction of milk grading on the basis of the health standard of the herd and the bacteriological condition of the milk set up a high standard of efficiency and had a far-reaching effect on the ordinary supply.

Clean milk investigations. Soon after the Research Institute was established at Shinfield, the attention of the staff was drawn to the loss to the industry through the souring of milk, and inquiries made in 1916–17 showed that the chief causes were wrong methods of production and handling. To find out how a better milk could consistently be produced was obviously a problem for the new Institute, but this subject could not be adequately studied until the Institute obtained its own farm, in 1920. Soon afterwards, several series of investigations were undertaken to obtain accurate information on the effect of different equipment and methods in the cowshed and the dairy on the cleanliness and keeping-qualities of the milk; also, the efficiency of certain equipment and methods was studied under practical conditions by the systematic examination of samples from farms producing the highest grades of milk. At this and later stages of the work the

knowledge, enthusiasm, and determination of Stenhouse Williams were of inestimable value.

The items of equipment studied in relation to the hygienic condition of the milk comprised the cowshed and the importance of sufficient light in the farm dairy, water-supplies, types of milking-pails, milking-machines, types of strainers and straining-materials, milk-coolers, thermometers, milk-churns, sources of steam (from primus stoves to pressure boilers) and chests for the steam sterilization of utensils; the methods studied included the cleanliness of the stall and cowshed at milking-time, dry grooming and washing of cows before milking, methods of milking, cleansing of milking-pails and all other utensils or apparatus with which the milk comes in contact, the efficiency of washing followed by scalding or steam sterilization, the use of chemical sterilizing agents, the temperature to which milk was cooled and the relationship between the temperature of the cooled milk and the temperature during storage or transport.

The results obtained showed how milk of high hygienic quality could be produced. Methods were found to be more important than equipment at many stages in the procedure, but the consistent use of the right methods was dependent on the understanding and conscientiousness of the worker. Adequate light and water, and clean utensils were found to be a universal essential, and the required degree of cleanliness could very rarely be attained without steam sterilization.

It is unnecessary here to recapitulate the results of these investigations in detail; they are to be found in numerous publications ranging from Ministry of Agriculture bulletins to rules for clean milk production issued by buyers of milk to their suppliers, and many excellent practical summaries are to be found in the equipment and the methods in daily use on innumerable farms throughout the country.

Educational activities. Having found out how to produce clean milk, the Institute had also to undertake educational work to get the knowledge distributed throughout the

country. For a number of years short courses in clean milk production and general farm hygiene were held at frequent intervals. These were attended by county dairy instructors and instructresses, sanitary inspectors, farmers, milk dealers, veterinary surgeons, and medical officers of health; demonstrations were given at agricultural shows; assistance was given in the organization and judging of county clean milk competitions; and, within a comparatively short space of time, the newer knowledge was easily available to every milk-producer in the country. The Institute also assisted materially in the formulation of standard laboratory methods for the bacteriological examination of milk, and in the establishment of the Advisory Bacteriological Service which is now operative in each agricultural educational province.

The educational activities throughout the country very soon reflected the new point of view. In those counties where instruction in cheese-making and butter-making was still desirable the work was continued but it ceased to be the chief feature; in these, and in many other counties where little or nothing had been done to provide advice on milk-production, additional staff was provided to assist farmers and their employees. Also, the farmers themselves responded readily; by means of participation in County Clean Milk Competitions and the encouragement given by purchasers who agreed to pay bonuses for milk of high hygienic quality, the equipment and methods employed on many farms were revolutionized.

Taints in milk. Accounts of the occasional presence of objectionable flavours in milk are to be found in the earliest writings on dairy subjects. While sometimes it is possible to identify a taint described a hundred years ago it is often impossible to accept the old opinions as to the cause of its appearance, and if to-day the true cause is still sometimes obscure it is better to enlist the services of the chemist and bacteriologist than to lay the blame on 'spells' and witches. By scientific study it has been shown that taints are due, as a rule, to the action of foods or plants eaten by the cow or to chemical or bacterial action in the milk, and work at

Shinfield and at other centres has dealt with all these causes.

The mode of development of a 'fishy' taint in milk following on the feeding of sugar-beet by-products has been investigated, and, as with foods such as marrow-stem kale and silage, it was found that the appearance of the taint could be prevented by giving these foods soon after milking. It was also shown at Shinfield that the presence in hay of weeds of the chamomile species (may-weeds) gave rise to an unpleasant tarry flavour in the milk.

The study by Mattick of another defect of milk, usually described as an oily or tallowy taint, showed that, though bacteriological action appeared to be the cause, chemical action was in fact responsible. This taint develops some 12–36 hours after the milk has left the farm, and by reason of this lapse of time it was thought at first to be due to bacterial action. But the taint was most prevalent during the winter, when the low temperature discouraged the growth of bacteria, and it was found, also, in samples of milk containing very few organisms of any kind, so further search for the cause was necessary. In one instance where the taint was present, the cooler was found to be old and worn, and when a new one was installed the taint disappeared. It was eventually proved that where the tinning was worn off, leaving an exposed surface of copper on the cooler or other utensil, the milk dissolved minute quantities of copper and these caused an oxidation of the fat in the milk which gave rise to the taint. This oxidation process, however, could not proceed when bacterial growth was active, and this accounted for the rare appearance of the taint during the summer.

Cheese problems. Although special attention has been given to problems arising in the production and handling of milk for sale, some of the difficulties of the cheese-maker and the butter-maker have been investigated. Faults in Stilton and Cheddar cheese, taking the form of discoloration of the ripened cheese, have often been the cause of serious loss to the farmer. In one investigation a survey was made of the conditions of milk-production

on a large number of farms supplying a Stilton cheese factory. These conditions were found to be bad, and bacteriological examination of the milk, the water-supplies, and the cheese showed the presence of many kinds of bacteria which could only have come from sources of contamination and which were capable of producing the objectionable discoloration in experimental cheese.

In Cheddar cheese a fault known as red or rusty spot was causing serious losses and investigations on the farms and in the laboratory showed that this discoloration was of bacterial origin. Under some conditions the causative organism grew in a colourless form and was quite harmless, and it was eventually shown that, if other organisms were excluded by adopting the hygienic precautions necessary for clean milk production, even if the red spot organisms were present they produced no colour and the cheese was normal.

These and other problems which have been studied at Shinfield have shown that Lloyd was indeed right when, in 1899, he surmised that cheese-making had also to deal 'to a large extent with bacteriological problems'. Investigations have also been undertaken into 'the science which underlies the existing practice of the best cheese-makers', but it appears that not only the chemist and the bacteriologist but the physicist, the engineer, and even the psychologist will have to work together for some years before the parts played by the various sciences can be elucidated, explained, and codified.

THIRD PERIOD, 1933–9

A study of the economic conditions in the dairy industry during recent years and the legislative and other measures introduced to control these conditions does not come within the scope of this essay, but the effect of the Milk Marketing Scheme on milk production must be considered.

Accredited milk. One of the main features of this scheme, which came into operation in October 1933, was the provision of a market for all the milk any farmer cared to

produce, and there is no doubt that this encouraged an increase in the production of milk for sale, and that sometimes in attaining increased production cleanliness and keeping-qualities were sacrificed. The Board administering the Scheme had also undertaken to stimulate the production of milk of higher hygienic quality, and as a means to this end the Accredited Producers' Roll scheme was inaugurated in 1935. Under this scheme, every producer who obtained a 'Grade A' licence received a bonus of 1*d*. per gallon on all milk sold through the Board.[1] Since the introduction of the grading of milk under the Milk (Special Designations) Orders of 1922 and 1923, the rate of qualification for Grade A licences had been slow, but now there was a marked change. Up to 1935, although a large number of farmers had improved their methods, there were only some 800 producers of this grade of milk; by the end of 1936 there were 20,000 and by the end of 1938 there were over 23,000, and their output represented some 35–40 per cent. of the total milk-production of the country.

Tuberculin-tested milk. When the Milk Marketing Board began operations in 1935, exemption from participation in the scheme was granted to producers of 'Certified' and 'Grade A (Tuberculin Tested)' milk, and, as economic conditions led to a gradual increase in the levies made by the Milk Board, many producers took steps to qualify for 'Tuberculin Tested' licences and gain the benefits of exemption. This exemption was withdrawn in 1937, and since October 1st of that year producers of 'Tuberculin-Tested' milk have been awarded a bonus of 2*d*. per gallon over the price of ordinary milk,[1] and they may also obtain a quality premium of 2*d*. per gallon from the buyer of the milk. These conditions have contributed to a marked increase in the production of the highest grade of milk; in 1933 there were only some 500 licences and by December 1938 there were over 3,300, and their production was about 6 per cent. of the total output.

[1] This bonus was increased by ¼*d*. per gallon on Oct. 1st, 1938.

In 1936 a new Milk (Special Designations) Order replaced that of 1923; by it the grade-names 'Certified' and 'Grade A (Tuberculin Tested)' were replaced by the designation 'Tuberculin Tested', and the name 'Grade A' by the designation 'Accredited'. In the new Order, also, the plate-count method of determining the bacteriological condition of milk was, for grading purposes, replaced by the methylene blue reduction test, which is less expensive, requires less time, and was considered generally more suitable for the classification of raw milks.

Attested herds. In 1935, also, the Ministry of Agriculture inaugurated a campaign to raise the health standard of dairy herds. The first step was the introduction of a scheme, known as the 'Attested Herds Scheme', whereby owners who had eradicated tuberculosis from their herds and who complied with stringent but necessary conditions received a Certificate of Attestation and were entitled to a bonus of 1*d.* per gallon on all milk sold through the Milk Marketing Scheme. In 1938, several amendments to the Scheme were introduced; one of these provided for financial assistance to meet part of the cost of tuberculin testing in herds with less than 10 per cent. of reactors, and with this additional aid the scheme has made excellent progress, especially in parts of Wales. The total number of Attested Herds of dairy cattle in England and Wales on February 1st, 1939, was 2,932.

One of the outstanding features of this third period has been the much greater attention given to milk as a food. Large-scale investigations have been carried out on the nutritive value of milk, with special reference to its chemical- and vitamin-content, and on the effect which the application of heat has on these qualities. At the National Institute for Research in Dairying a new department has been created for laboratory work on this and related subjects, and valuable results have been obtained. Further mention of this work, however, does not fall within the scope of this essay.

The forty years covered in this essay have seen many changes and many improvements in the practice of milk-

production, due in part to legislation and in part to the application of the results of scientific research. The status of the industry has been raised to at least the level of any other branch of agriculture, knowledge on many fundamental points has been accumulated and made readily available, the conditions of production and the quality of the product have been vastly improved, and a sound foundation has been laid for the research, education, and enlightened practice which will be needed to meet the problems of the future.

AGRICULTURE AND NATIONAL HEALTH

By SIR JOHN BOYD ORR

ADVANCES in the physiology of nutrition in the last twenty years have altered our ideas of food-requirements and moved the agricultural problem from a background of glut to a background of scarcity. Prior to the advent of the 'newer knowledge of nutrition', it was assumed that if people had sufficient palatable and digestible food to satisfy hunger, physiological needs would be satisfied. Hence, dietary requirements were estimated from the data of calorimetric investigations on energy-expenditure under different conditions, and of chemical analyses of foodstuffs which determined their energy-yielding value.

With the rise of the standard of living the whole population of this country has, for many years, been lifted above the level of starvation. Since the beginning of the present century, even the poorest, except in relatively few exceptional circumstances, have been able to obtain sufficient food to satisfy hunger. A diet of bread, sugar, and other cheap carbohydrate foods, vegetable fats, and cheap protein foods, sufficient to supply all the calories needed, is within the purchasing-power of the whole population, even of the unemployed.

Among the poor the diet is largely restricted to these cheap foodstuffs which satisfy hunger at low cost. But, as the standard of living rises and purchasing-power increases, the consumption of the more expensive animal products, fruit, and vegetables increases. Compared with pre-War days, the consumption of these, with the exception of milk, has increased roughly by about 50 per cent.

In the nineteenth and early part of the twentieth century the increase in consumption of the more expensive foods as the standard of living rose, and the increase in consumption of all foods as the population increased, kept pace with increased supply brought about by the application of science to production and transport. But following on the world economic crisis of 1929, world markets were

flooded with foodstuffs which could not be sold at former prices. It looked as if there had been a sudden increase in production. The Minister of Agriculture expressed a view common to those who control the means of production and distribution of commodities when he said we must think out a new technique for dealing with glut. The technique applied was the destruction of the surplus and the control of production. Both in Europe and America young animals were killed, acreage under cultivation reduced, and restrictions placed on imports.

As the United Kingdom was the world's greatest market for food, surpluses from other countries were dumped on our market with disastrous effects on prices. The 1931 and 1933 Agricultural Marketing Acts were designed to raise and maintain prices by controlling production and imports. These Acts were based on the assumption that there was a surplus of unneeded food. As there was obviously sufficient food in the country to satisfy hunger, it was considered that no undue hardship would be inflicted on the general community if, in the interests of agriculture, the glut were eliminated and the total national supply restricted to a level at which prices would be profitable to the producer and the trader.

Subsequent investigation of the cause of collapse of prices in 1930 has thrown doubts upon the assumption that the agricultural slump was due to over-production. The following table, taken from the League of Nations *World Production and Prices, 1934*, shows that between 1929 and 1932 agricultural production did not vary by much more than 1 per cent., whereas industrial activity decreased by about 30 per cent.

INDEX NUMBERS OF WORLD PRODUCTION (1925–9 = 100)

	1925	*1926*	*1927*	*1928*	*1929*	*1930*	*1931*	*1932*	*1933*	*1934**
All agricultural products . . .	97	97	99	103	103	104	103	104	104	101
Crude foodstuffs .	97	97	99	104	103	104	102	105	104	102
Industrial activity .	91	94	99	104	112	100	89	78	88	96

* Estimate.

Mr. R. R. Enfield, in his Presidential Address to the Agricultural Economics Society in 1936, after a review of the whole position came to the conclusion that 'a fall in demand has been at the root of the severe decline in the price of agricultural products. . . . The extensive unemployment in Europe and America, coupled with wage cuts and shorter hours, is the greatest single cause of world depression in agriculture, so much so, that if world unemployment were suddenly to cease as a result of general economic recovery with all that that implies, it might reveal a shortage of supply in many agricultural commodities now over-produced.'

The glut was due not so much to increased world production as to decreased world consumption owing to the fall in purchasing-power. This raises the question, At what level should the total market-supply of any foodstuff be maintained? If we regard national requirements as the amount necessary to satisfy hunger, then there has always been a surplus, because the wealthy have always enjoyed a diet above that minimum level. As the standard of living rises, consumption of the more expensive foodstuffs increases. A rise in the standard of living can be brought about by a fall in the price of commodities without a corresponding fall in income just as effectively as by a rise in income without a corresponding rise in the price. The consumption of the cheapest foods that satisfy hunger, such as bread and sugar, remains relatively constant, irrespective of fluctuation in prices. But a reduction in the price of other foodstuffs is followed by an increase in consumption. It has sometimes been asserted that milk does not follow this rule, but all the available evidence shows that, even in the case of milk, consumption is affected by price. The reduction in the retail price of milk from 3*d.* to 2½*d.* per pint by the Co-operative Society in Shettleston was followed by an increased consumption of 13½ per cent. More recently (1937), the English Milk Marketing Board made an experiment to ascertain the effect of price on demand. The Board accepted 8*d.* per gallon for the milk and the distributors 8*d.* per gallon for distributing it in

some distressed areas. Consumption in these areas increased by 61 per cent. A similar result was obtained with potatoes. In an experiment done by the Potato Marketing Board at Bishop Auckland a reduction in the retail price of potatoes from 7*d.* to 4*d.* per stone was followed by an increase in consumption of 69 per cent.

It is obvious that we are not dealing with a saturated market. The degree of saturation depends entirely upon the ratio between purchasing-power and retail price. In the slump of 1929 and 1930, if the fall in the wholesale prices had been immediately reflected by a commensurate fall in retail prices, the glut would have disappeared, and the fall in the wholesale prices would not have been so great.

The fact that the capacity of markets to absorb foodstuffs fluctuates with purchasing-power raises a fundamental difficulty in devising schemes for adjusting supply to economic demand. If the supply were satisfactorily adjusted in any given year there would be a glut the following year if industrial depression became worse and purchasing-power fell. The only way to avoid unsaleable surpluses is to adjust the retail price to the purchasing-power of the poorest class, in which case there will be no restriction of consumption due to fall in purchasing-power, and we should then be able to adjust the supply to the food-requirements of the nation which would be constant, irrespective of trade booms and slumps.

It may be assumed that the first objective of any Government in devising schemes affecting the national food-supply should be to ensure that all classes of the community would be able to obtain a diet adequate for health. If this principle be accepted, then, in a system of supply regulation, demand would be interpreted as the amount needed to meet the requirements of the whole population and not as the amount allowed to come on the market to maintain any given price, and in schemes for fixing retail prices the price would be fixed in accordance with the purchasing-power of the poorest and not at a level which producers and traders consider necessary to main-

tain profits. The profits of the producers could be safeguarded by other means, such as a direct subsidy or a guaranteed price not necessarily related to the retail selling price.

Let us consider national food-requirements. The 'newer knowledge of nutrition', which has been built up since the War, has shown that many common diseases, much ill health and poor physique are due to deficiencies of specific nutrients, mainly vitamins and minerals. These are present in greatest abundance in animal products, especially milk, dairy products, and eggs, and in fruit and vegetables which, in consequence, have been termed 'protective' foods. In the last few years standards of diets stating the amount of 'protective' foods required to meet the physiological needs have been drawn up by various authorities. The best known are the Stiebeling standard (1933), based on investigations done by a Division of the Agricultural Department of the United States, the 'minimum diet' of the British Medical Association (1934), and the League of Nations standard (1935). Of these, the most important is the League of Nations standard. It was drawn up by an International Committee of fifteen experts of international reputation drawn from different countries in Europe and the United States. That standard has been approved by the Medical Research Council of this country, by the Government Advisory Committee on Nutrition, and by bodies of similar standing in other countries. It can now be taken as the international standard. It is an optimum diet, that is to say, it is a diet which will not merely prevent the onset of gross ill health which can be detected by ordinary clinical methods; it is a diet which will enable a race to attain its full inherited capacity for health and physical fitness so far as that can be obtained by proper feeding. The following specimen diet for a child of 3 to 5 years of age gives an indication of the kind of diet recommended: milk, 1 litre; 1 egg; 30 gm. meat, fish, or liver; 100 gm. green leafy vegetables; 150 gm. potatoes; a daily supply of fruit or raw vegetables; 3 gm. cod-liver oil. These 'protective' foods supply 980 Calories

of the 1,400 Calories required, the supplementary energy-yielding foods needed to make up the difference being supplied by fats, butter if possible, and cereals. This, of course, is only an example of the kind of diet which will supply everything needed for health. An unlimited number of equally good diets might be drawn up with slightly different proportions of the foodstuffs named or even including foodstuffs not named, but they would all have an equally high proportion of 'protective' foods.

When the diet of different classes in this country is compared with any of these standards it is found that the average consumption of 'protective' foods is sufficient for health amongst the wealthy, but as income falls consumption decreases. According to the recent investigation by Sir William Crawford (1938) the food expenditure of eight millions of the population is below the cost of the British Medical Association 'minimum diet' and, according to *Food, Health, and Income*, the diet of roughly half the population falls below the League of Nations standard.

There is a correlation between health and physique and diet. The incidence of diseases of malnutrition, such as rickets, increases as family income falls and the diet becomes worse. The infant mortality rate, a good indication of the health of a community, is about 30 per 1,000 live births among the wealthy, about 70 among the poorer-paid working class, and over 100 among the unemployed.

Ill health and poor physique due to faulty diet are not confined to this country. In a recent investigation in Australia, done by a Council appointed by the Government, it was found that in Melbourne 21·7 per cent. of children of pre-school age showed evidence of malnutrition, and in 192 families investigated in New South Wales the state of nutrition was unsatisfactory in 36·6 per cent. The Council observes that milk, dairy products, fruit, vegetables, and fish are not available in sufficient quantities and at low enough prices. In the United States it was found that 60 per cent. of the diets of Negro families in the South were in need of improvement, and, in some regions, it was found that the diets of 40 to 60 per cent.

of white families were below the standard required for health. In most countries throughout the world the national dietary is much worse than in the United Kingdom, the United States, and Australia. On the other hand, the diet, health, and physique of the people of New Zealand and the Scandinavian countries are probably better than in this country, though even in these countries there is a good deal of malnutrition due to faulty diet.

The connexion between purchasing-power, diet, and health has been studied by Committees of the League of Nations, and it has been found that bad diet is accompanied by bad health, and the main cause of bad diet is poverty. The Rt. Hon. S. M. Bruce, who took a deep interest in these investigations, concluded that 'poverty is correlated to disease, ill health, and premature death'. Associated with poverty there are many disabilities which affect health, but the evidence of recent investigations suggests that the most important is faulty diet.

Like other democratic countries, we are faced with the twin problems of depression in agriculture and malnutrition due to poverty. Owing partly to the fact that as a nation we are more interested in trade than in the direct promotion of human welfare, and partly to the fact that the National Farmers' Union has a greater political power than the unorganized masses who live at or below the 'poverty line', the Government, so far, has done more to relieve the plight of agriculture than to reduce malnutrition due to poverty. But the plight of agriculture has not been over-emphasized. For many years agricultural produce has, on an average, been sold below all-in costs which should include depreciation of buildings, equipment, and land and a wage for the farm workers equivalent to that of other skilled workmen. Agriculture has been living partly on its capital and partly at the expense of the agricultural labourer. There is no doubt that cost of production could be reduced by making the industry more efficient. But the industry needs more money to make itself more efficient. On the whole, a high state of efficiency is to be found in large farms where the farmer is not

only a farmer but is also a middleman deriving part of his income from trades allied to agriculture. The small working farmer, with no income except what is derived from his farm, needs more money to enable him to bring his land, buildings, and equipment up to a state of efficiency.

The Government has introduced different kinds of schemes to assist agriculture. What agriculture needs is more money, and the value of the schemes can be estimated by the amount of additional money they have brought to the industry. But in the interest of different classes of the community we have also to consider where the money comes from. In the case of the cattle subsidy the money is obtained from the Treasury, in which case different classes pay for the support of agriculture in proportion to their ability to pay. But in the case of the wheat subsidy the money is obtained from an indirect tax on bread which, in the present year, will amount to $\frac{3}{4}d.$ on the four-pound loaf. The milk scheme has increased the retail price of milk. Schemes for the restriction of imports and production maintained or raised retail prices. Money obtained from an increase in retail prices is paid by families not in proportion to their income but in proportion to the amount of food they consume. Hence, an increase in prices is of little importance to the wealthier part of the community who spend only a small proportion of their total income on food. It is, however, of great importance to working-class families, because the lower the family income the higher is the percentage spent on food. In the case of the poorest families, expenditure on food accounts for 50 per cent. or more of the total income. The burden of increased prices, therefore, falls heaviest on working-class families with children. The rise in prices reduces their consumption of 'protective' foods and, to that extent, adversely affects their health.

For public health reasons we need to increase the supply of 'protective' foods. According to Lord Astor and Mr. Seebohm Rowntree, to bring liquid-milk consumption up to the level required for health we need two and a half

million more cows, which would increase milk-production by about 65 per cent. We need an even larger increase in the supply of fruit and vegetables. We need more eggs, more meat, and more fish. But these additional foodstuffs will not be consumed unless they are brought within the purchasing-power of the whole community. A diet which contains sufficient of these 'protective' foods would cost, at present retail prices, about 7*s.* 6*d.* to 10*s.* per head per week according to district and season. That cost puts such a diet beyond the purchasing-power of at least 25 per cent. of the population. But some of the measures which help agriculture have been designed to restrict the supply and raise prices. This brings us up against the apparent conflict between the interests of agriculture and the interests of health. This conflict has arisen because agriculture and health are dealt with by different Government Departments as if production and consumption had no relation to each other. The time has come to consider the production and consumption of food as different aspects of the one problem. When this is done, it is obvious that we need a new national policy which will reconcile the apparently conflicting interests of agriculture. Such a policy would involve the nationalization of Agricultural Marketing Boards, making them responsible through the Houses of Parliament to the whole community. The Boards would need to be given money from the National Treasury to enable them to bridge the gulf between what the farmer needs to induce him to produce the additional foodstuffs required and what the poor can pay. No one believes that the money cannot be found. Mr. Colin Clark has estimated that the national income has increased by one thousand million pounds per annum since 1930. One-tenth part of that increase would be sufficient to initiate a national food policy. The Boards would need to be given power to control the key points of wholesale distribution, especially the processing centres, such as bacon factories, slaughter-houses, milk and egg depots, round which they would be able to reorganize marketing. At these depots the Boards would accumulate supplies of food. With a

national pool of foodstuffs and a pool of funds they would be able to offer a guaranteed price to farmers which would call forth the large amount of additional 'protective' foods which the nation needs. They would also be able to reduce retail prices and maintain level prices all the year round.

A combined health and agricultural policy on these lines would bring prosperity to agriculture with increased employment on the land. It would bring about a rapid improvement in national health and physique. The cheapening of foodstuffs would mean a rise in the standard of living which would be greatest in the case of the poorest who spend the largest proportion of their income on food. It would thus help to put a bottom into poverty.

This policy would help to carry the nation over periods of trade depression because the amount of food needed is the same in depression as in prosperity. In a period of depression with low purchasing-power the grant from the National Exchequer would need to be increased. The increased amount of money in circulation to support the food policy would act as a fly-wheel to carry trade over the slump period. The stability of agriculture and the food trade would help to stabilize the whole trade in the country. Further, the worst effects of trade depression would be prevented because, whatever the state of employment, both the low-paid workers and the unemployed would be assured of an ample supply of food to maintain themselves and their children in a state of health and physical fitness.

There are twenty-one countries in the world which have set up National Nutrition Committees to investigate the state of nutrition of the people and ascertain what adjustments are needed in the agricultural and food policy to bring the national dietary up to the League of Nations standard. There is little doubt that if a world war is averted national food policies will be devised to attain the objectives outlined above. If these objectives are attained there will be a great extension of agriculture and an increase of international trade. A nutritional policy might well be the spear-head for a movement for economic

prosperity based on the satisfaction of human needs and the promotion of human welfare. The United Kingdom, with the world's greatest market for food, might well take the lead in a movement which will ultimately become world-wide.

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